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ASSESSING CHEMICAL RELEASES AND WORKER EXPOSURES FROM A FILTER PRESS

by

James Scott
Keith Sherban
Mary Marshall
Southwest Research Institute
San Antonio, Texas 78284

EPA Cooperative Agreement CR813355
SwRI Project 01-1236

Project Officer

Dennis L. Timberlake
Water and Hazardous Waste Treatment Research Division
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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Chemical releases and worker exposures associated with the filtration of an industrial wastewater sludge were characterized. The filter was a recessed chamber filter press with an open filtrate discharge system. Chemical releases and worker exposures for a selected chemical were measured over four operational cycles and various aspects of the filtration operation believed to influence the measurement values were documented. The filter press and ancillary systems are described along with worker exposures and durations for each stage. Ventilation patterns around the filter press were monitored. The worker's time-weighted average exposures to total copper (low vapor pressure, highly insoluble form) during the 113-minute operational cycle ranged from 3.1 to 25 ug/m3. The sludge feed and filter cake copper concentrations were approximately 0.1 and 1.0 weight percent. A noticeable difference in worker techniques was observed which may account for the large range of inhalation exposures during the cake removal stage. During this stage, the inhalation exposures ranged from 11 ug/m3 to 130 ug/m3. The manual removal of filter cake comprised only 15% of the time in an average filtration cycle, but produced 72% of the worker's inhalation exposure.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing of research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report details the rationale, events, findings, data quality, and interpretations of the first in-plant assessment study conducted as part of the joint research effort between the U.S. Environmental Protection Agency and Southwest Research Institute. The research program is titled "Engineering and Toxic Characterization Studies and Development of Unit Operation Predictive Models for New Chemicals" (Cooperative Agreement CR813355). This in-plant assessment study determined the worker exposures and chemical releases associated with a filter press operation in an industrial wastewater treatment facility. These data and operational details such as stage activities and durations will be combined with pilot plant findings and other in-plant assessment studies to develop a predictive model for the Premanufacture Notice (PMN) review system.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

Chemical releases and worker exposures associated with the filtration of an industrial wastewater sludge were characterized. The filter was a recessed chamber filter press with an open filtrate discharge system. Chemical releases and worker exposures for a selected target chemical were measured over four operational cycles and various aspects of the filtration operation believed to influence the measurement values were documented. This report contains an account of the methods implemented to collect and analyze samples, including the quality control requirements and results, and the procedures used to obtain all of the field data.

The filter press and ancillary systems are described herein. The three sequential stage activities comprising each filtration cycle are described along with operational procedures, worker scenarios, and worker exposures for each stage. Ventilation patterns around the filter press are presented as well as the supply and exhaust air flow rates for the filter press room. Sampling results of the feed stream, filter cake, and filtrate effluent are presented together with the batch sizes (volume and mass basis) of the filtration cycles to further define the operational conditions.

The worker's time-weighted average exposures to total copper (low vapor pressure, highly insoluble form) during the 113-minute operational cycle ranged from 3.1 to 25 $\mu g/m^3$. The sludge feed and filter cake copper concentrations were approximately 0.1 and 1.0 weight percent. A noticeable difference in worker techniques was observed which may account for the large range of inhalation exposures during the cake removal stage. During this stage, the inhalation exposures ranged from 11 $\mu g/m^3$ to 130 $\mu g/m^3$. The manual removal of filter cake comprised only 15% of the time in an average filtration cycle, but produced 72% of the worker's inhalation exposure.

This report is submitted in partial fulfillment of Cooperative Agreement CR813355 by Southwest Research Institute under the partial sponsorship of the U.S. Environmental Protection Agency. The field work described in this report occurred on December 21 and 22, 1987.

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LIST OF ABBREVIATIONS

ACGIH -- American Conference of Governmental Industrial Hygienists
cc -- cubic centimeters
cm -- centimeter
cm^2 -- square centimeters
Cu -- copper
EPA -- U.S. Environmental Protection Agency
eV -- electron volt
g -- grams
GSD -- geometric standard deviation
hr -- hour
I.D. -- inside diameter
kg -- kilograms
kPa -- kilopascals
L -- liters
Lpm -- liters per minute
m -- meters
m^2 -- square meters
m^3 -- cubic meters
M_C -- mass of material in the filter cake
M_F -- mass of material in the filtrate
M_S -- mass of material in the sludge feed
mg -- milligrams
min -- minutes
mL -- milliliters
mm -- millimeters
NIOSH -- National Institute for Occupational Safety and Health
O.D. -- outside diameter
ORD -- Office of Research and Development
OTS -- Office of Toxic Substances
P&ID -- piping and instrumentation diagram
PMN -- Premanufacture Notice
PVC -- polyvinyl chloride
QA -- quality assurance
s -- seconds
SwRI -- Southwest Research Institute
TLV -- threshold limit value
TWA -- time-weighted average
μg -- micrograms

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SECTION 1

INTRODUCTION

RESEARCH PROJECT

In August 1986, a joint research effort was undertaken by the U.S. Environmental Protection Agency (EPA) and Southwest Research Institute (SwRI) to develop database models for use in predicting chemical releases and worker exposures from select filtration and drying unit operations used in chemical manufacturing processes. The research consists of in-plant assessment studies, pilot plant experiments, and literature reviews. The in-plant assessment studies provide data on the chemical releases and worker exposures that occur in manufacturing and processing facilities. Regarding filtration unit operations, in-plant assessment studies of filter presses were accorded a high priority for the project.

The database models developed will be applicable for EPA's Premanufacture Notice (PMN) review system. For each study the chemical being monitored will be a surrogate for a hypothetical PMN new chemical in order to evaluate the worker exposures and chemical releases from the unit operation. Thus, there is no requirement to select an operation which has a toxic chemical, provided that the physical properties of the chemical can be extrapolated to the hypothetical PMN new chemical.

Over the course of the study, it is desirable to select different chemicals for similar unit operations. Differences between chemicals for various studies of this cooperative agreement should include ranges of vapor pressures, ranges of molecular weights, and inorganic and organic chemicals. The majority of in-plant studies were targeted to have organic chemicals with high molecular weights and low vapor pressures.

DEFINITIONS

For this research, "chemical release" has been defined as any intentional or unintentional discharge (liquid, solid, or gaseous form) other than the product stream which contains the target chemical of the process in a given unit operation at specified operating conditions. "Worker exposure" has been defined as the quantity of a target chemical available to affect an unprotected worker by inhalation, dermal, and/or ingestion routes during a defined time period under specified conditions. Worker exposure is not equivalent to a dose. "Dose" is defined as the quantity of a target chemical delivered to the specific organ(s) of a worker. The "target chemical" is the substance of interest being processed by the specific unit operation. A "system boundary" is established to include those process components that comprise the unit operation being studied. The system boundary is process dependent, not site dependent; two different sites may have the identical system boundaries if the same process is being done at both locations. A "sealing point" is a joint or junction for connecting static or dynamic parts of a piece of equipment (e.g., body or pipe flanges). An "in-plant assessment study" is the performance of field sampling activities in manufacturing or processing plants to collect data for two primary purposes: (1) to develop the database on chemical releases and worker exposures for a particular unit operation, and (2) to reproduce actual plant situations in pilot plant experiments that enable the performance of more detailed studies.

FILTRATION PROCESS OVERVIEW AT PLANT 50

Plant 50 is an electronics manufacturing facility. The large volume and quality of the industrial wastewater generated by the manufacturing processes makes treatment within the plant economically and environmentally attractive to the company. The plant's waste treatment area processes different wastewater streams which contain high concentrations of soluble metals (see Figure 1). The wastewaters are chemically treated in the waste treatment area to precipitate metal salts and to adjust the pH. The metal salts are collected within clarifiers, and the clarifier sludges are pumped into storage tanks. The metal-laden sludges are pumped from the storage tanks on an "as-needed basis" to the filter presses. A separate room housing two filter presses (referred to as Press A and Press B by the treatment personnel) abuts the west wall of the waste treatment facility (see Figures 2, 3, and 4).

The sludges can be processed by the two filter presses, either separately (unsynchronized) or jointly (one press is being filled while the other is being cleaned), depending upon the waste loadings (liters per day) being imposed upon the treatment facility. While all of the individual wastewater streams are chemically treated in discrete systems, the sludges from the clarifiers can be pumped into common storage tanks. The three sludges from the metals rinse, ammonium rinse, and chromium rinse treatment systems are normally called "General Sludge" by the personnel. However, sufficient flexibility had been used in the treatment design to permit the isolation of any one of these three sludges into one storage tank and the subsequent processing of this one sludge through a dedicated filter press.

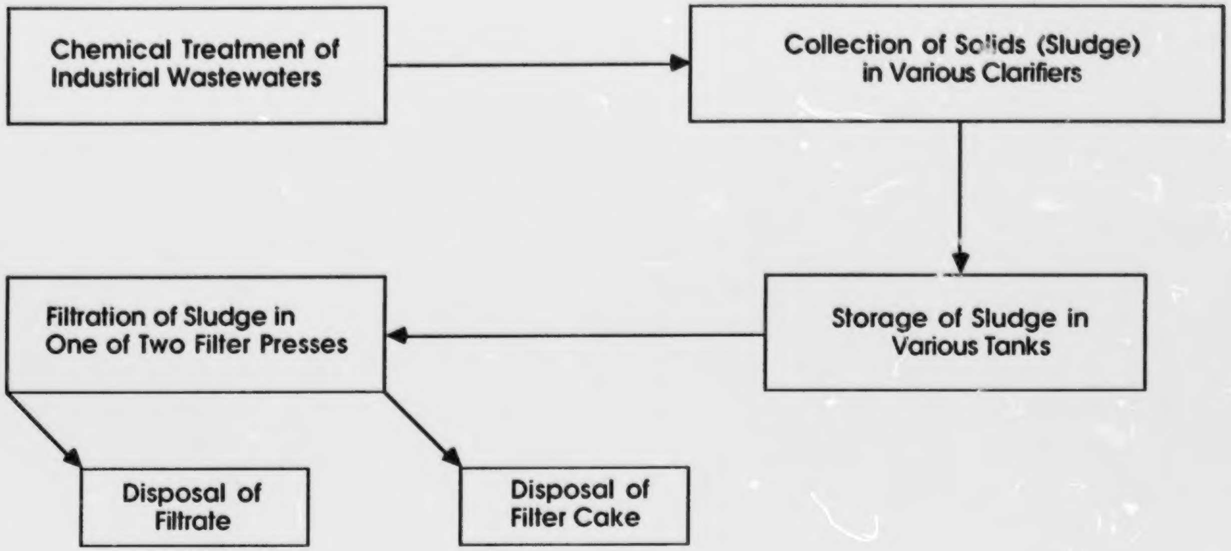

Chemical Treatment of Industrial Wastewaters
Collection of Solids (Sludge) in Various Clarifiers
Storage of Sludge in Various Tanks
Filtration of Sludge in One of Two Filter Presses
Disposal of Filtrate
Disposal of Filter Cake

Figure 1. Process flow diagram for Plant 50.

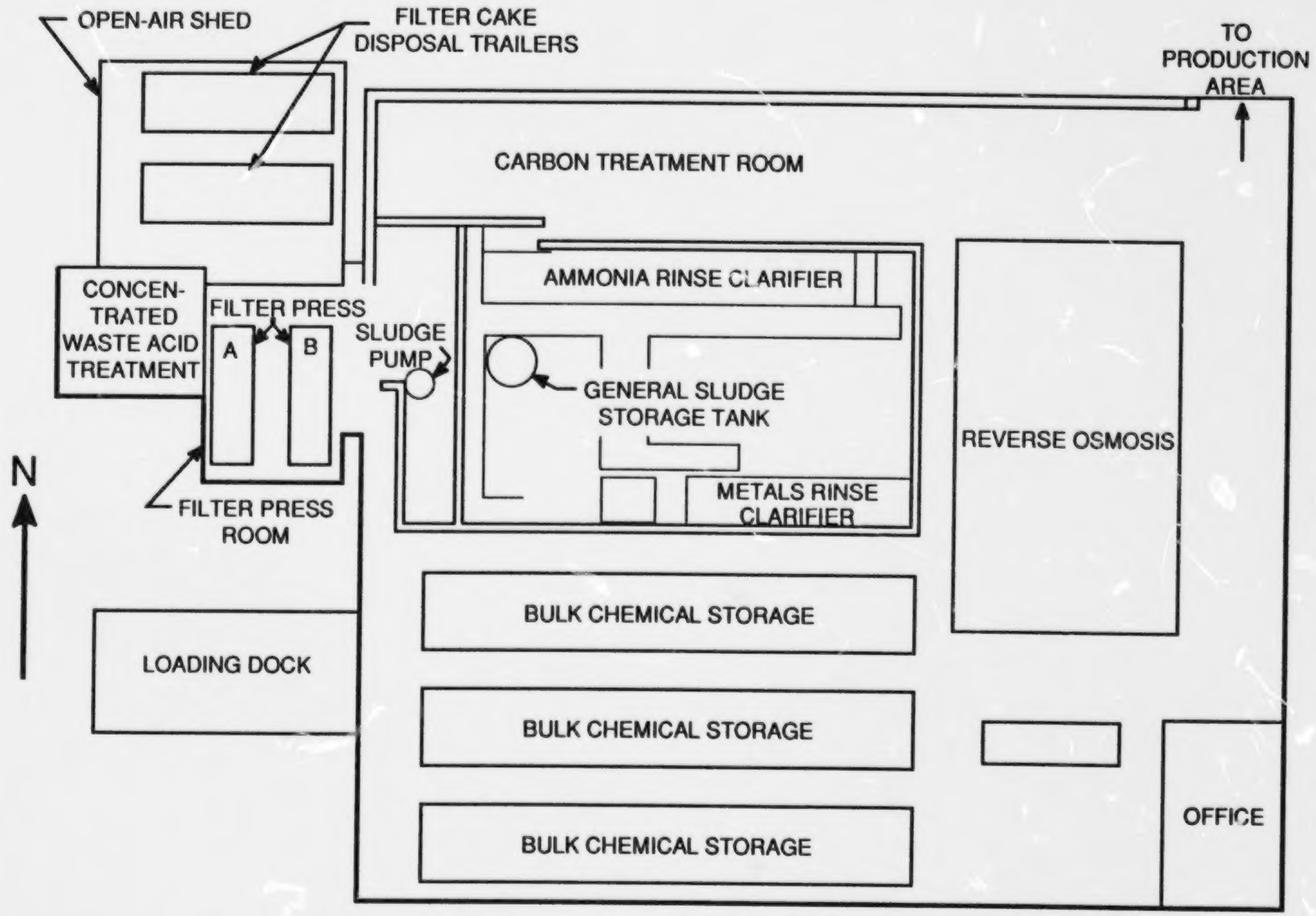

OPEN-AIR SHED
FILTER CAKE DISPOSAL TRAILERS
TO PRODUCTION AREA
CARBON TREATMENT ROOM
CONCEN-TRATED WASTE ACID TREATMENT
FILTER PRESS
A
B
SLUDGE PUMP
AMMONIA RINSE CLARIFIER
GENERAL SLUDGE STORAGE TANK
REVERSE OSMOSIS
N
FILTER PRESS ROOM
METALS RINSE CLARIFIER
BULK CHEMICAL STORAGE
LOADING DOCK
BULK CHEMICAL STORAGE
BULK CHEMICAL STORAGE
OFFICE

Figure 2. Plant 50 Industrial Waste Treatment Facility.

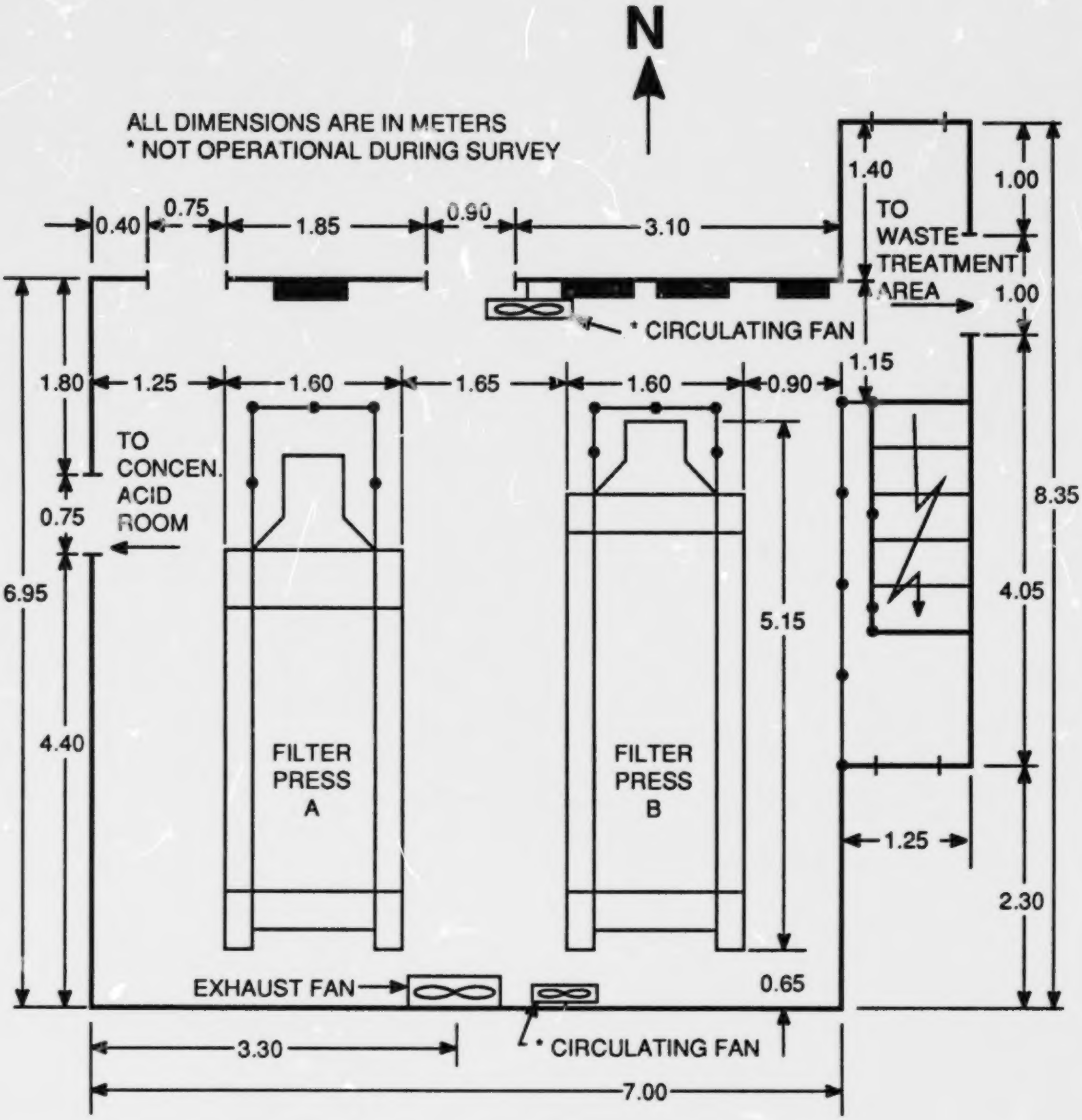

N
ALL DIMENSIONS ARE IN METERS
* NOT OPERATIONAL DURING SURVEY
0.40
0.75
1.85
0.90
3.10
1.40
1.00
TO WASTE TREATMENT AREA
1.00
* CIRCULATING FAN
1.15
1.80
1.25
1.60
1.65
1.60
0.90
TO CONCEN. ACID ROOM
0.75
6.95
4.40
5.15
8.35
4.05
FILTER PRESS A
FILTER PRESS B
1.25
2.30
EXHAUST FAN
0.65
3.30
* CIRCULATING FAN
7.00

Figure 3. Plan View of Filter Press Room.

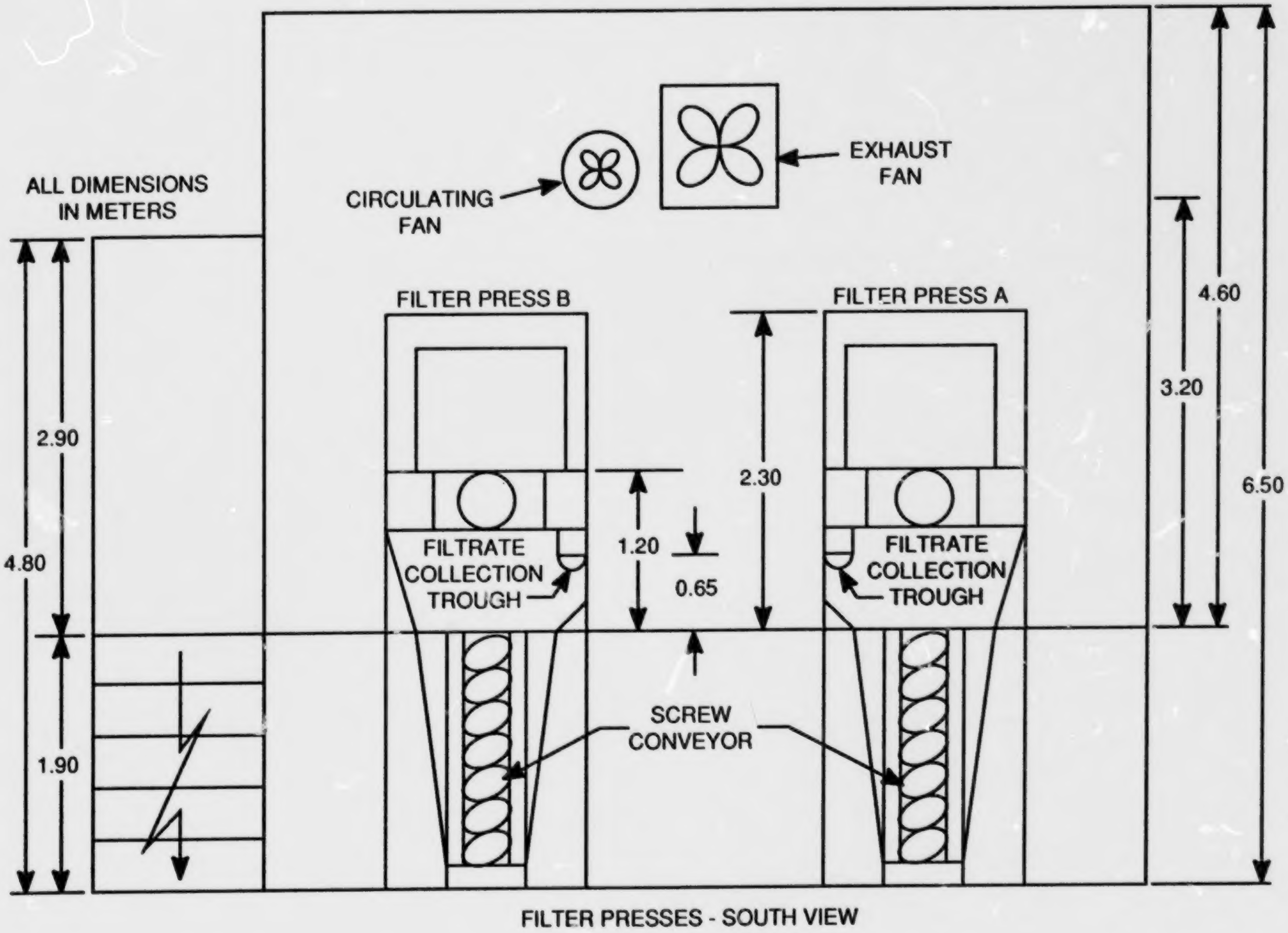

ALL DIMENSIONS IN METERS
CIRCULATING FAN
EXHAUST FAN
FILTER PRESS B
FILTER PRESS A
FILTRATE COLLECTION TROUGH
FILTRATE COLLECTION TROUGH
SCREW CONVEYOR
2.90
4.80
1.90
1.20
0.65
2.30
3.20
4.60
6.50
FILTER PRESSES - SOUTH VIEW

Figure 4. Elevation of Filter Press Room.

The average total duty of the filter presses is 15,000 to 26,500 liters of sludge per day. Typically, five to ten filtration cycles are required to process the contents of a filled storage tank. The waste treatment area employs 15 workers that are spread over three, eight-hour work shifts. Normally, one operator is assigned to the filter presses. Previous analyses of the filter cake by Plant 50 personnel indicated that copper represented the highest concentration of any of the metals.

The decision to conduct an in-plant assessment of a filter press in Plant 50 with copper as the target chemical was predicated upon the following:

1. Only one filter press would be operating during all sampling activities. (Thus, worker exposures and chemical releases could be attributed to the operation of that single unit operation.)

2. A sufficient quantity of sludge (about 10,000 liters) could be isolated and made available to supply four filtration cycles. (Four observations would provide at least 95% confidence that the worker exposure geometric mean is estimated within an order of magnitude when the geometric standard deviation (GSD) is less than or equal ($\leq$) to 2.0; and with at least 90% confidence when the GSD $\leq$ 2.6. Isolation of the sludge insured that the physical and chemical characteristics of the sludge feed to the filter press would be constant during the four filtration cycles.)

3. The same filter press could be used for all four filtrations. (Thus, the filtration capability inherent to the filter press was a constant factor during the four filtration cycles.)

4. Operators were always available and willing to provide process and work task information to the field survey team.

5. The location of the filter presses in a small, separate room greatly facilitated the establishment of a system boundary, measurement of ventilation patterns, and identification of background air contaminants.

6. Copper in air, water, and solids is easily measured by atomic absorption spectrophotometry.

7. Around-the-clock operation of the filter press enabled sampling activities to be conducted to discern differences in work techniques among various employees and also identify any patterns that existed among different shifts.

SECTION 2

CONCLUSIONS

The Plant 50 assessment study of a recessed chamber filter press documented worker exposures and chemical releases associated with a selected target chemical processed by the filtration unit operation. The target chemical, total copper, was in a highly insoluble form with a low vapor pressure. The actual field work (data collection activities) was conducted on December 21 and 22, 1987.

The workers' time-weighted average (TWA) exposures to total copper over the 113-min average duration of the unit operation ranged from 3.1 to 25 $\mu g/m^3$. The American Conference of Governmental Industrial Hygienists' (ACGIH) 1987-88 threshold limit value (TLV) for 8-hr exposures to copper dust and mist is 1 mg/m^3 air.

The total copper concentrations in the sludge feed and the filter cake were approximately 0.1 and 1.0% by weight, respectively. Therefore, it is uncertain whether the low worker exposures measured were solely attributed to the operational characteristics of the filter press or were a reflection of the low total copper concentrations.

The area of the room most frequently occupied by the workers was also the area that received the least air circulation. The air flow rate and distribution pattern inside the filter press room remained relatively constant throughout the study.

Data from this research also indicate that a worker's technique in removing the filter cake may be an important factor in determining a worker's exposure to within one order of magnitude. The range of inhalation exposures during the cake removal stage was 11 $\mu g/m^3$ to 130 $\mu g/m^3$. A noticeable difference in worker techniques was recorded for the high and low exposure readings.

The sludge filtering stage showed great variability among the work paths taken by the filter press operators but little difference among their resultant exposures (geometric mean exposure for the four sludge filtering stages was 4.1 $\mu g/m^3$). The sludge filtering stage comprised roughly one-third of the 113 min needed to complete an average filtration cycle.

The filter cake drying stage, which comprised slightly more than 50% of the time for the filtration cycle, was largely unattended by the operators and, therefore, it contributed very little to their exposures. The working time near the filter press was 3 minutes, and the geometric mean of the inhalation exposures to airborne copper was 1.6 $\mu g/m^3$.

Although manual removal of filter cake from the chambers of the filter press comprised only 15% of the time in an average filtration cycle, it produced 72% of the workers' exposures to copper during the filtration operation.

Dermal exposures to total copper were not quantitated. Observations of the operators' work practices indicated that their dermal exposures were probably very low and effectively eliminated through their use of work gloves when removing the filter cake.

Total chemical releases from the filter press were estimated to be 2.1 g of copper or 0.1% of the total copper mass that was processed through the unit operation. While the mass of chemical in the filtrate could be measured, the mass of chemical released in spills or leaks of the feed material and filter cake could not be quantified. The study's data indicate that leaks or spills of feed material or filter cake can be a greater potential source of chemical releases than from the total filtrate effluent for insoluble filter cake products.

Using a mass balance to calculate total copper processed through the filter press was not an effective method for measuring the individual chemical releases. The sampling and analytical errors associated with the mass balance measurements did not permit accurate calculations of the relatively small masses represented by the individual chemical releases.

SECTION 3

RECOMMENDATIONS

The in-plant assessment study of a filter press unit operation at Plant 50 yielded data that provided insight into worker exposures and chemical releases. Additional in-plant assessment studies are needed to fully characterize filter presses for the PMN database. Pilot-scale experiments should be conducted using different worker scenarios and target chemicals to quantify ranges of exposures and chemical releases that can occur by varying these two variables.

For a future in-plant assessment study of a filter press, any one or more of the following criteria should be considered in the selection process:

- A liquid, high molecular weight, organic target chemical should be studied.
- An operation with a more concentrated target chemical (cake product) in the feed stream should be used.
- A larger filter press (one requiring two operators to remove the filter cake) should be used.

SECTION 4

DESCRIPTION OF THE FILTRATION UNIT OPERATION

A schematic diagram of the filtration unit operation is shown in Figure 5. The piping and instrumentation diagram (P&ID) is shown in Figure 6. The study's focus was the filter press; however, it was necessary to evaluate ancillary equipment for complete data interpretation. These auxiliary devices were not included in the system boundary because they may change from site to site.

SLUDGE FEED TANK

The sludge feed tank was manufactured by Lancy Laboratory, constructed of fiberglass and in good condition. The tank was cylindrically shaped, 2.44 meters in diameter, with a rounded bottom (a spherical section) and was supported off the ground by metal legs. The depth of the cylindrical part of the tank was 3.05 meters and the rounded bottom had a depth of 0.46 meters. The volume of these zones of the tank were 14,200 liters and 1,110 liters, respectively. The top of the tank was open to the plant atmosphere while the outlet, centrally located at the bottom, was connected to 9 cm (3 1/2 inches) O.D. polyvinyl chloride (PVC) pipe. The tank was located in the waste treatment area, approximately 6 meters from the entrance to the filter press room.

Sludge from the metal rinse clarifier is typically pumped to the sludge feed tank approximately every 3 hours. However, prior to the initiation of this study, the inlet valve to the sludge feed tank was closed and all sludges were diverted to another storage tank. Since no additional sludge entered the sludge feed tank during the field sampling activities, the sludge in that tank comprised a constant supply source for the filter press during the study. The feed tank did not have a mechanical agitator but instead was mixed by compressed air blown through a PVC pipe to the bottom of the tank (the air bubbled from the end of the PVC pipe). It was estimated from the movement of the sludge that approximately 70 percent of the tank's contents were being mixed.

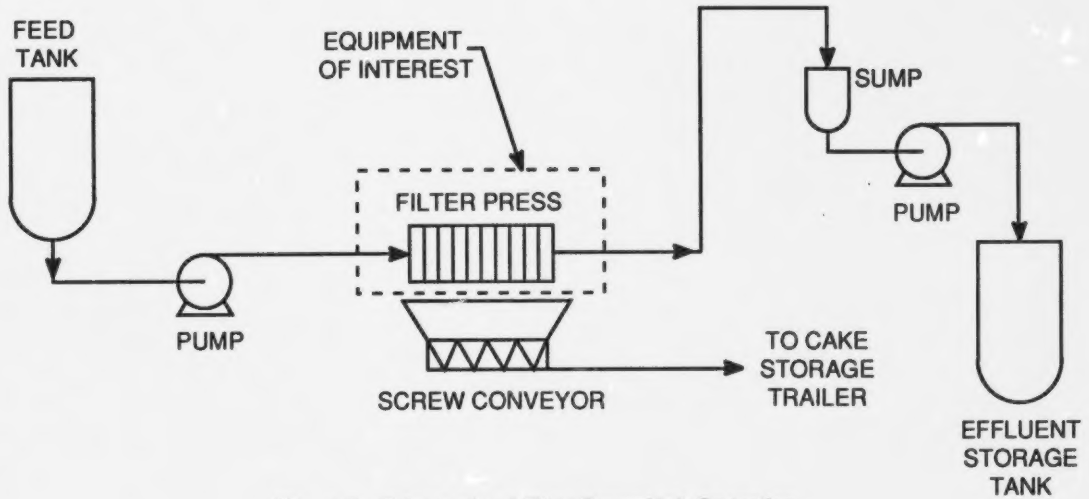

FEED
TANK
PUMP
EQUIPMENT
OF INTEREST
FILTER PRESS
SCREW CONVEYOR
TO CAKE
STORAGE
TRAILER
SUMP
PUMP
EFFLUENT
STORAGE
TANK

Figure 5. Schematic of Filter Press Unit Operation.

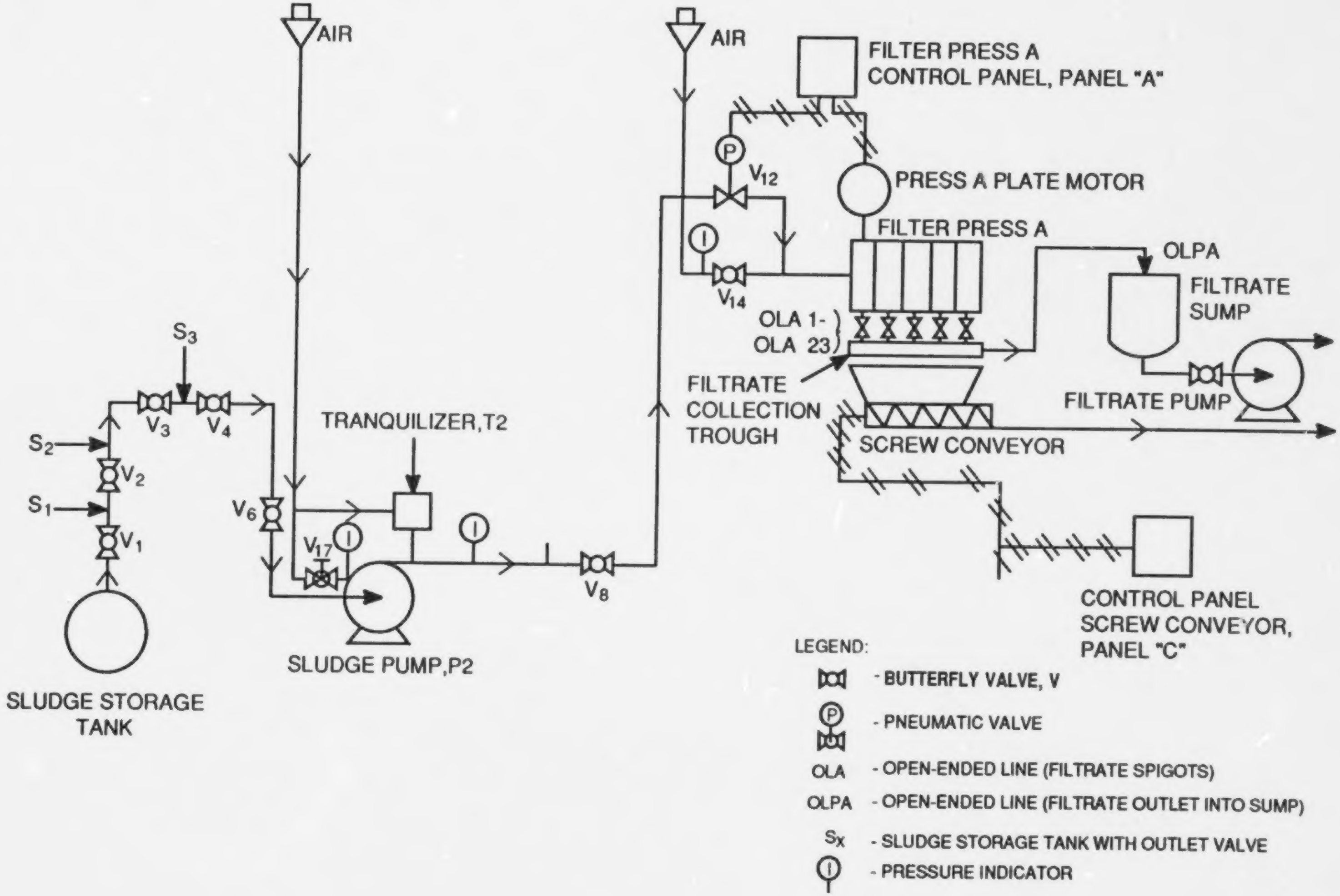

AIR
AIR
FILTER PRESS A CONTROL PANEL, PANEL "A"
P
V_{12}
PRESS A PLATE MOTOR
FILTER PRESS A
OLPA
FILTRATE SUMP
V_{14}
OLA 1-
OLA 23
FILTRATE COLLECTION TROUGH
FILTRATE PUMP
SCREW CONVEYOR
S_3
V_3
V_4
S_2
V_2
S_1
V_1
V_6
TRANQUILIZER,T2
V_{17}
V_8
SLUDGE STORAGE TANK
SLUDGE PUMP,P2
CONTROL PANEL SCREW CONVEYOR, PANEL "C"
LEGEND:
- BUTTERFLY VALVE, V
- PNEUMATIC VALVE
OLA - OPEN-ENDED LINE (FILTRATE SPIGOTS)
OLPA - OPEN-ENDED LINE (FILTRATE OUTLET INTO SUMP)
S_X - SLUDGE STORAGE TANK WITH OUTLET VALVE
- PRESSURE INDICATOR

Figure 6. Piping and Instrumentation Diagram.

PIPING AND VALVES TO SLUDGE FEED PUMP

The PVC piping connecting the sludge feed tank and the sludge feed pump was 9 cm O.D. and 7 cm I.D. and approximately 6.7 m in length. In the pipe connecting the tank and the pump were 5 Asahi butterfly valves (shown as V1, V2, V3, V4, and V6 in Figure 6). These valves were also constructed of PVC and were the only valves opened and closed during the in-plant assessment study.

Three other pipes from sludge storage tanks in the waste treatment area also fed into the pipeline to the sludge feed pump. Each of these pipes from the other sludge storage tanks (S1, S2, and S3 in Figure 6) had a valve which was closed during the in-plant study.

SLUDGE FEED PUMP

The sludge was transferred from the sludge feed tank to the filter press by a diaphragm pump made by the Wilden Pump and Engineering Company (Model #M15-FO-NE-NE-NE) and was also located in the waste treatment area approximately 2.5 m from the entrance to the filter press room. The pump casing was of steel construction, in good condition, and marked with an identification tag which was dated March 1987. The outer dimensions of the pump were 81 cm tall, 46 cm wide, and 41 cm deep. The sludge inlet and outlet ports were flanged and connected to 9 cm O.D. flanged pipe sealed with a rubber gasket and secured with 4 bolts.

The pump was turned on and off at Control Panel A and driven by compressed air (792 kPa). The inlet air line was 2.2 cm O.D. copper tubing, while the exit line for the air was 3.1 cm O.D. PVC tubing. The exit line was also connected to a breather (41 cm long). The pump was rated for a maximum capacity of 950 liters per minute.

TRANQUILIZER

A device called a tranquilizer was used to dampen the vibrations in the pipe line caused by the sludge feed pump. The tranquilizer was manufactured by the Warren Rupp Company (Model # TA2 Type [V-1-A]) and was constructed of cast aluminum. The tranquilizer was cylindrical in shape (25 cm in diameter and 51 cm in length) and was connected to the sludge feed line 0.3 m beyond the sludge feed pump. A compressed air line was connected to the tranquilizer. Plant personnel questioned about the tranquilizer could not provide a clear explanation about the working mechanisms of this device.

PIPING TO THE FILTER PRESS

The piping from the tranquilizer to the filter press was constructed of steel, 9 cm O.D. and approximately 25 m in length. There were two valves, V8 and V12, in this stretch of piping. All of the piping used welded joints.

FILTER PRESS

The filter press was manufactured by Eberhard Hoesch & Sohne in June 1972 (see Figure 7). The overall condition of the press was good. The base frame of the press was constructed of steel and weighed 5200 kg. The approximate outer dimensions of the press were 5.0 m long, 1.6 m wide and 2.3 m tall. The "front" of the filter press contains the hydraulic ram and is closest to the north wall of the filter press room. The "rear" of the filter press is where valve V14 is located (near the south wall of the room).

The press was originally equipped with 26 polypropylene recessed plates; however, 3 plates had become damaged over the years. Thus, 23 plates (or 22 chambers) were studied. The square plate outer dimensions are 1 m in length and width, and 4.5 cm thick (see Figure 8). The filtration cloth dimensions are 0.914 m in length and width, minus the four equilateral triangles whose base and height are each 0.152 m. Each chamber is formed by two such filter cloths, thus the available surface area for filtration per chamber is 1.58 m^2:

[(length x width) - 4 corners (1/2 x base x height)] x 2 cloths/chamber

$$= \{[(0.914\ m)(0.914\ m)] - (4)[(0.5)(0.152\ m)(0.152\ m)]\} \times 2$$

$$= (0.79\ m^2 \times 2) \text{ per chamber}$$

Thus, the total filtration area available is 34.8 m^2 (1.58 m^2/chamber x 22 chambers). The chamber thickness was 4.0 cm resulting in a total filtration volume of 0.70 m^3 (0.04 m x 0.79 m^2 x 22 chambers).

The feed entered at the front of the press and proceeded through the central feed slot of each plate. The maximum permissible inlet feed pressure was 979 kPa. The actual inlet feed pressure was unknown.

Each filter cloth consisted of two pieces (approximately 1 meter square) of polypropylene fabric connected to each other by a short tubule made of the same fabric (see Figure 9). A filter cloth covered both sides of one recessed chamber plate, with the tubular section passing through the central feed slot in the plate. The two square pieces of the filter cloth were connected

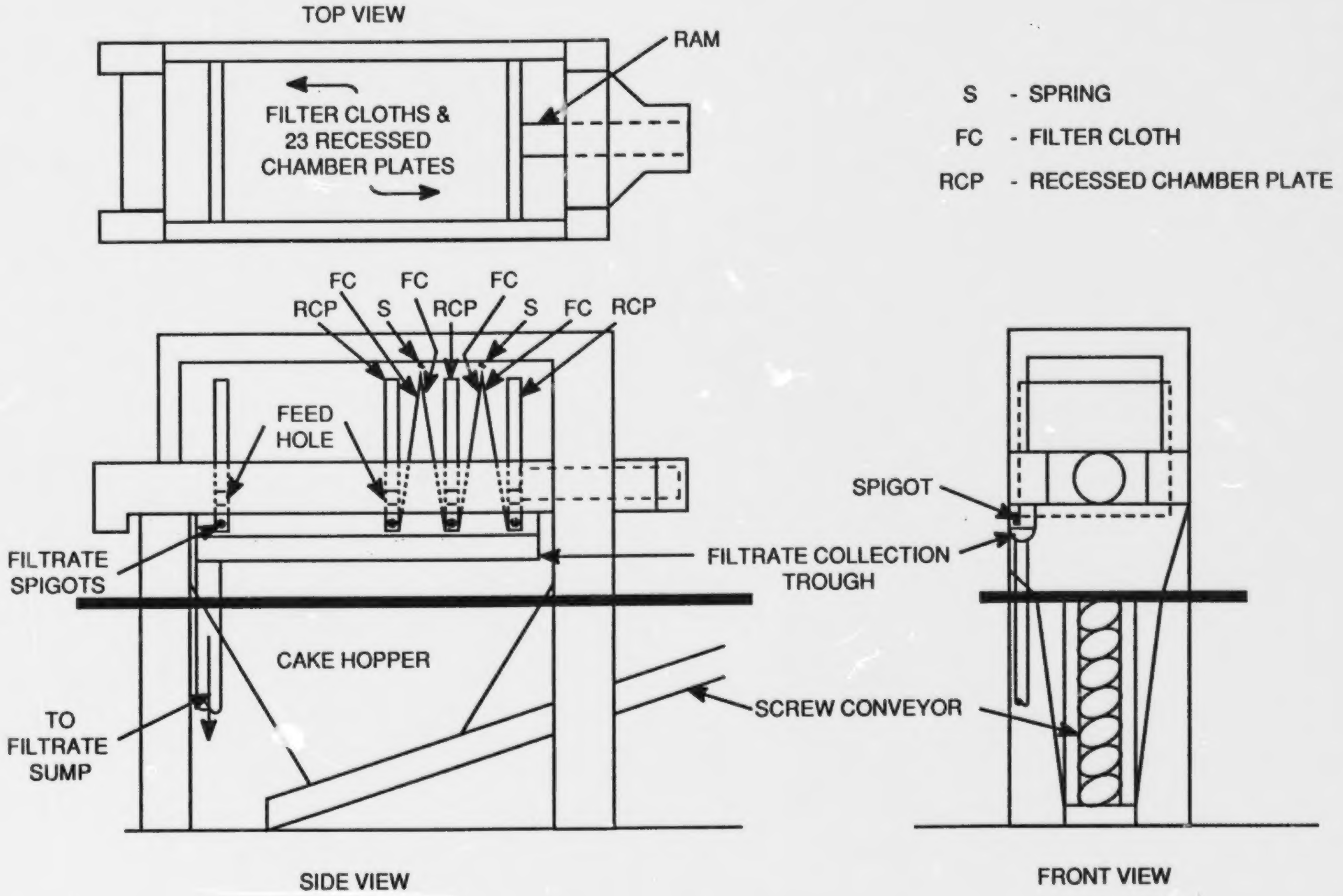

TOP VIEW
RAM
FILTER CLOTHS &
23 RECESSED
CHAMBER PLATES
S - SPRING
FC - FILTER CLOTH
RCP - RECESSED CHAMBER PLATE
FC
FC
FC
RCP
S
RCP
S
FC
RCP
FEED
HOLE
FILTRATE
SPIGOTS
CAKE HOPPER
TO
FILTRATE
SUMP
SCREW CONVEYOR
SPIGOT
FILTRATE COLLECTION
TROUGH
SIDE VIEW
FRONT VIEW

Figure 7. Filter Press A.

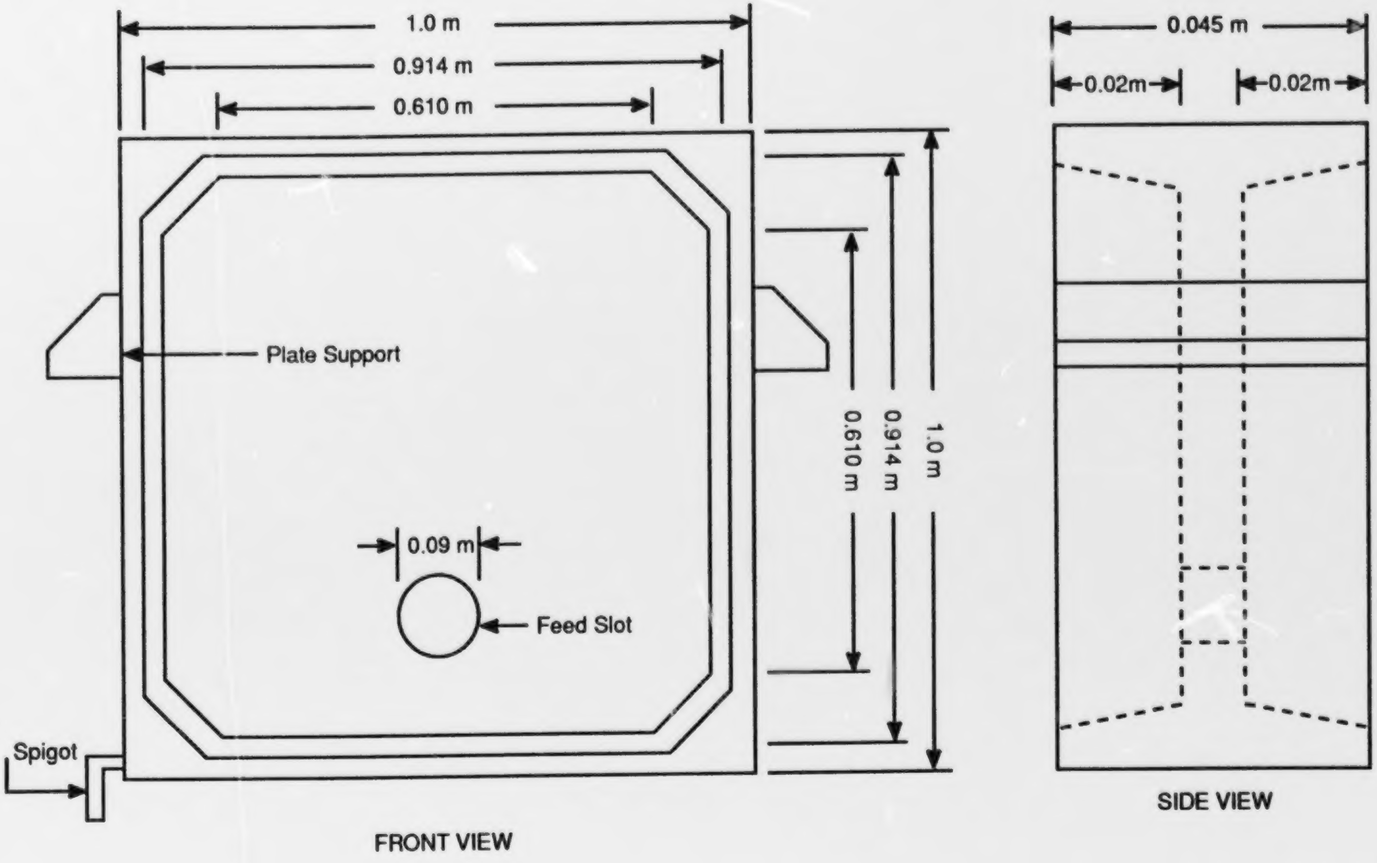
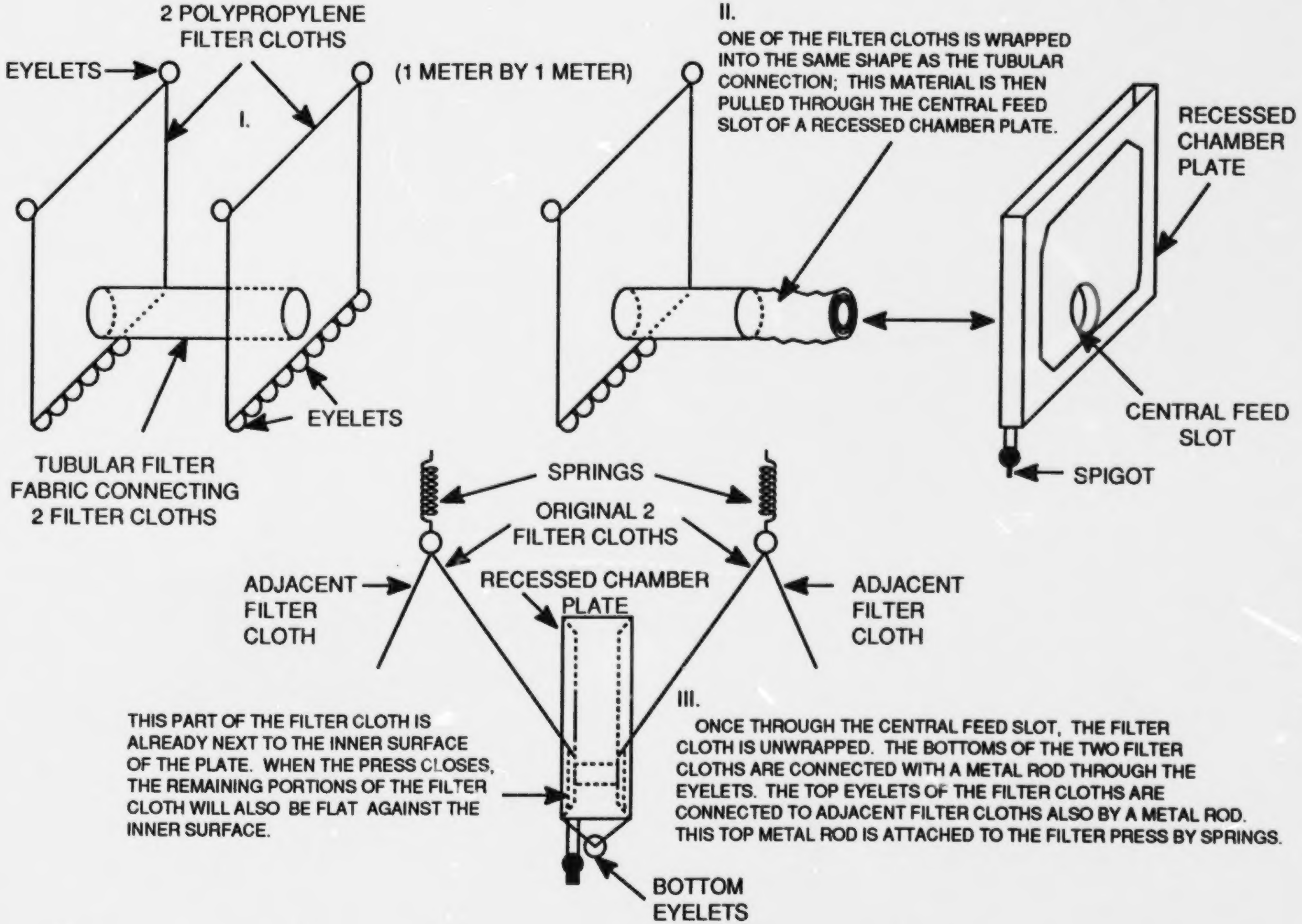

1.0 m
0.914 m
0.610 m
Plate Support
0.09 m
Feed Slot
Spigot
1.0 m
0.914 m
0.610 m
FRONT VIEW
0.045 m
0.02m
0.02m
SIDE VIEW

Figure 8. Recessed Chamber Plate.


2 POLYPROPYLENE
FILTER CLOTHS
EYELETS
(1 METER BY 1 METER)
I.
EYELETS
TUBULAR FILTER
FABRIC CONNECTING
2 FILTER CLOTHS
II.
RECESSED
CHAMBER
PLATE
CENTRAL FEED
SLOT
SPIGOT
SPRINGS
ORIGINAL 2
FILTER CLOTHS
ADJACENT
FILTER
CLOTH
RECESSED CHAMBER
PLATE
ADJACENT
FILTER
CLOTH
III.
BOTTOM
EYELETS

ONE OF THE FILTER CLOTHS IS WRAPPED INTO THE SAME SHAPE AS THE TUBULAR CONNECTION; THIS MATERIAL IS THEN PULLED THROUGH THE CENTRAL FEED SLOT OF A RECESSED CHAMBER PLATE.

THIS PART OF THE FILTER CLOTH IS ALREADY NEXT TO THE INNER SURFACE OF THE PLATE. WHEN THE PRESS CLOSES, THE REMAINING PORTIONS OF THE FILTER CLOTH WILL ALSO BE FLAT AGAINST THE INNER SURFACE.

ONCE THROUGH THE CENTRAL FEED SLOT, THE FILTER CLOTH IS UNWRAPPED. THE BOTTOMS OF THE TWO FILTER CLOTHS ARE CONNECTED WITH A METAL ROD THROUGH THE EYELETS. THE TOP EYELETS OF THE FILTER CLOTHS ARE CONNECTED TO ADJACENT FILTER CLOTHS ALSO BY A METAL ROD. THIS TOP METAL ROD IS ATTACHED TO THE FILTER PRESS BY SPRINGS.

Figure 9. Configuration of Assembled Filter Cloths and Recessed Chamber Plates.

together underneath the recessed chamber plate by a metal rod inserted through eyelets on the bottoms of the two square pieces. The top of the unit of filter cloth was also supported by a metal rod running through an eyelet. The rod was attached to two springs, one at each end of the rod, which were supported by the frame (two I-beams) approximately 0.5 m above the top of the recessed chamber plate.

Attached to the bottom of each plate was a short piece of pipe and a valve. The filtrate (during the filtration stage) and the air (during the filter cake drying stage) exited the filter press via these pipes into a collection trough. The valves on the pipes were originally designed to be used to stop the flow of filtrate in case the filter cloth became damaged during the filtration stage; otherwise, unfiltered sludge would pass through the press. However, the valves were rarely used and had become non-operational over the years. If a filter cloth becomes damaged at this facility, the operator must stop filtering, clean the press, and replace the damaged filter cloth.

The press was also originally equipped with a filtrate collection trough, however the trough had been replaced with a 20 cm O.D. PVC pipe, with a tangentially (or length-wise) jagged hole cut at the top (approximately 10 cm wide). The total length of trough was 2.21 m. The filtrate that collected in the trough flowed toward the south end of the trough to an exit port which was connected to 10 cm O.D. pipe which ran to the filtrate sump located at the sublevel.

This filter press was equipped with a hydraulic ram system for opening and closing. The controls for the pump for the hydraulic ram system were located at Control Panel A. When the press was closed, the hydraulic line for the ram reached 17,500 kPa. (The maximum permissible pressure for this system was 19,590 kPa.) The press was opened by retracting the hydraulic ram and then using an automated plate shifting device. Each plate was opened one at a time to allow the cake collected between two plates to fall into the filter cake hopper directly below the filter press. The filter cake hopper contained a screw conveyor which transported the cake to storage trailers in a separate room. The automated plate shifting device consisted of an electric motor which drove a chain with a series of small arms which caught the edge of the next plate to be opened. The toggle switch that turned the electric motor on and off was connected to a cord which ran the length of the press. Once the mechanical arm hooked the plate, the operator pulled the cord connected to the toggle switch. The switch was manually-controlled in the "ON" position by the pulling of the cord. Once the plate was transferred to the remaining cleaned plates resting against the ram, the cord was released and the motor consequently was turned off. The distance between each opened plate was approximately 0.5 m.

FILTRATE SUMP

The filtrate sump was 1.22 m in height and 0.66 m square. The sump was constructed of fiberglass and in good condition. The walls of the sump were 1.27 cm thick. Three open end lines lead into the sump: two 10 cm O.D. pipe, one each from presses A and B, and a 7.5 cm O.D. pipe from a scrubber for the concentrated waste acid room. Note, the scrubber line was closed during the time of this study to prevent contamination. At the bottom of the sump was an exit port which was connected to a piece of 6 cm O.D. PVC pipe by 0.6 m long. This pipe connected to the sump pump which was activated by a level control inside the sump. The working depth (distance between the high level switch and the low level switch) of the level control was 25.4 cm.

FILTRATE SUMP PUMP

The filtrate sump pump used to transfer the filtrate from the sump to the effluent tank was a diaphragm pump manufactured by Wilden Pump and Engineering Company (Model # M8/PT/TF/TF/PT). It was located on the sublevel approximately 0.6 m from the filtrate sump. The casing of the pump was constructed of polypropylene and Kynar. The pump was in good condition and had an identification tag dated August 1985. The filtrate inlet and outlet ports were flanged and connected to 6 cm O.D. PVC tubing. The flanged ends were sealed with a rubber gasket and secured with 4 bolts.

The pump was driven by compressed air (550 kPa). The inlet air line was 1.3 cm O.D. copper tubing, while the outlet air line was 3.2 cm O.D. PVC tubing.

PIPING TO THE FILTRATE EFFLUENT TANK

The piping from the filtrate sump pump was constructed of PVC, 6 cm O.D., 4.6 cm I.D., and approximately 35.6 m in length.

FILTRATE EFFLUENT TANK

The filtrate effluent tank was exactly the same size as the sludge feed tank (see sludge feed tank description for further details). The top of this tank was also open to the plant atmosphere. This tank was approximately 3 meters east of the sludge feed tank in the waste treatment area.

SECTION 5

OPERATING PROCEDURES

Below is a description of the operating procedures for the filtration unit operation studied. The operation has been broken into three stages: sludge filtering, filter cake drying, and filter cake removal. Refer to Figure 6 (the piping and instrumentation diagram) as the operation is described.

SLUDGE FILTERING

1. At Control Panel A, the operator closed the press by switching the hydraulic ram on. The ram pushed the plates until they reached the rear of the press.

2. The ram continued to apply pressure to the closed set of plates until the pressure in the hydraulic line reached 17,500 kPa.

3. The operator opened pneumatic valve V12 at Control Panel A to control the flow of sludge into the press.

4. Valve V4 was opened. (Valves V1, V2, V3, and V6 were opened prior to the study.) With these valves open, the sludge feed could flow from the sludge feed tank.

5. Valve V8 was opened next. This allowed the flow of the sludge feed from the sludge feed pump to the filter press.

6. Valve V17 was opened. Valve V17 controlled the flow of air to sludge feed pump P2. The starting of the pump signaled the onset of the filtering stage.

7. Pump P2 transported the sludge to the filter press. Filter cake collected in the recesses of the press and filtrate exited the open end lines (OLA1 - OLA23) extending from each plate. Filtering continued until the press operator subjectively determined to shut the operation down. Shut-down was usually signaled by a noticeably slowed output of the open ended lines.

8. Valve V17 was closed. This action ceased the flow of air to the sludge feed pump P2 and tranquilizer T2.

9. Valves V8 and V4 were closed. This prevented the flow of sludge feed to the press.

FILTER CAKE DRYING

1. Valve V12 was closed at Control Panel A. This prevented the air used to dewater the cake from flowing into the pipe for the sludge feed.

2. Valve V14 was opened to start the flow of compressed air (736 kPa) into the recessed chambers of the filter press to dewater the filter cake. The cake was allowed to dry for approximately one hour.

3. Valve V14 was closed to stop dewatering.

FILTER CAKE REMOVAL

1. At Control Panel A, the switch was turned to retract the hydraulic ram. As the hydraulic ram retracted, the first recessed chamber opened and the cake in this chamber fell into the filter cake hopper.

2. The filter cloth was cleaned by the operator using a wooden pole. (A more detailed description of the technique used to clean the filter cloth is presented beginning on page 46.)

3. The next plate was transported from the set of plates, at the rear of the press, to the ram, at the front of the press, by the automated chain driven mechanism. This allowed the cake to fall from the second recessed chamber.

4. The filter cloth in this chamber was cleaned by the operator. This process of sliding one plate at a time toward the ram, the filter cake falling into the filter cake hopper, and the operator cleaning the filter cloth, continued until all 22 recessed chambers were cleaned.

5. The closing of the press signaled the onset of the next filtration cycle.

CLEANING OPERATIONS

Since the filter press processes a waste stream in which both the filter cake and filtrate are discharged to their respective disposal receptors, the operators do not clean the filter press equipment between filtration operations. According to information furnished by the operators, the filter cloths are replaced on a semi-annual basis.

SECTION 6

DATA COLLECTION METHODS

GENERAL

All data collected regarding worker exposures and chemical releases were categorized according to the three primary filtration stages: (1) sludge filtering stage during which the sludge feed was pumped into the filter press, (2) cake drying stage which encompassed the blowing of compressed air through the filter cake while it was still retained inside the recessed chambers, and (3) cake removal stage which included the emptying of filter cake from the recessed chambers and the cleaning of any cake residue from the filter cloths inside the chambers. The operators accomplished a filtration operation when they completed all three of these stages. Worker exposures were assessed during four cycles of the filtration operation, and chemical release measurements were taken during the first three of these cycles. A separate evaluation of the emissions from sealing points was performed during the sludge filtering stage in the fourth cycle of the filtration operation.

Several circumstances implemented for the in-plant assessment warrant special or repeated emphasis:

1. Filter press A was the only press utilized to process the sludge selected for the study.

2. Filter press B was never in operation while the study was being conducted.

3. The sludge processed through filter press A during the study was from a single storage tank containing metals rinse sludge. No other materials were added to the contents of the sludge storage tank during the course of the entire study. Between the third and fourth cycles of the filter press monitored in the study, Press A was utilized to process a different waste sludge. That particular filtration operation was excluded from the study since it involved a dissimilar sludge.

4. Only one operator per shift was assigned to the filter press room covered by the survey and this individual

accomplished all three stages of the filtration operation. In addition, the operator was the only employee of Plant 50 (excluding the plant's industrial hygienist who assisted the survey team) that remained inside the filter press room for the filtration operations. In total, data for this study were collected during 4 consecutive 8-hour work shifts with 3 different operators.

5. The primary methods used by survey team members to document data were preprinted forms and bound notebooks. Still photographs and videotapes were taken of many of the field activities.

VENTILATION

A Kurz 441M Air Velocity Meter (serial number PCE24091) was utilized to measure the air velocities at supply and exhaust openings, as well as at various locations within the filter press room. This meter gives air velocity in readings corrected to standard meters per second. In the temperature range present in the filter press room, the instrument's accuracy was plus or minus 2 percent of full scale. The meter was set on the 0-1.5 meters per second scale when measuring air velocities at doorways and in the room, while the 0-6 meters per second scale was utilized for the measurements at the exhaust fan. The velocity meter was calibrated by the manufacturer on May 22, 1987, using a calibrated mass flow meter traceable to National Bureau of Standards. The meter was inspected by the manufacturer on October 12, 1987 before shipment to SwRI and the calibration due date is October 12, 1988.

To determine the average air velocities at the supply and exhaust openings, the openings were divided into a number of equal areas as illustrated in Figure 10. A face velocity measurement was obtained at the center of each area and the values were then arithmetically averaged. Since the velocity was not usually constant at any one measuring point in the doorways, a mean velocity between the upper and lower readings was estimated.[1] The opening to the exhaust fan was covered by a bar grill. Therefore, utilizing a reduction factor of 0.78 for this type of covering recommended by the manufacturer in the velocity meter's operating manual, the actual flow rate into the exhaust fan was only 78 percent of the measured flow rate at the exhaust grill.[2]

Finally, smoke tubes were utilized to chart gross air movement within the filter press room. Particular attention was paid to the distribution of air entering and exiting the room as well as to the air patterns within the work areas normally occupied by the operators.

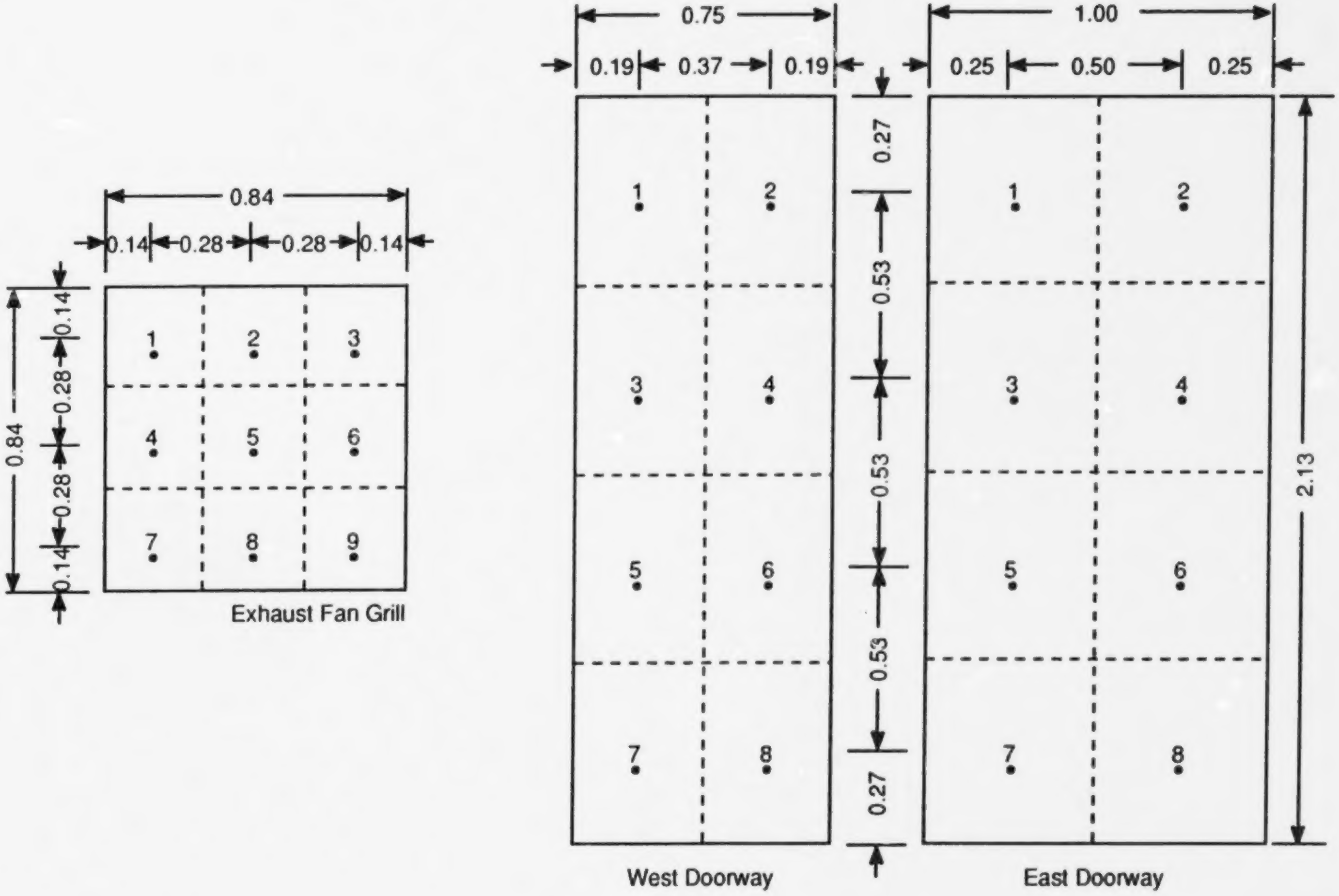

0.84
0.14
0.28
0.28
0.14
0.84
0.14
0.28
0.28
0.14
1
2
3
4
5
6
7
8
9
Exhaust Fan Grill
0.75
0.19
0.37
0.19
0.27
0.53
0.53
0.53
0.27
1
2
3
4
5
6
7
8
West Doorway
1.00
0.25
0.50
0.25
2.13
1
2
3
4
5
6
7
8
East Doorway

Figure 10. Air velocity measurement points for supply and exhaust openings.
(All dimensions are in meters.)

WORKER SCENARIOS

The objectives for observing and documenting the actions taken by workers during the total filtration operation were to:

1. Determine the duration of inhalation and dermal exposures to the workers during each of the three stages (sludge filtering, cake drying, and cake removal) that comprise the filtration cycle.
2. Identify the techniques or actions that workers used to accomplish the filtration operation and assess how their methods could influence their exposures.

Two field data sheets were utilized to obtain the information needed to achieve the above objectives. First, on a diagram of the filter press room the location of the worker was charted as the individual filtration tasks were performed (see Figure A-1). A grid was overlaid upon the diagram to assist in referencing these locations. A second data sheet (see Figure A-2) was utilized to annotate the time that the employee occupied a given location, the body position, arm or head movements that occurred as the operator accomplished the various work duties, and any other details concerning the employee's activities that could subsequently influence the inhalation or dermal exposure. Notation of the personal protective equipment worn by the operator was also made on the second data sheet.

Exposures were considered to have occurred during those periods of time in which the operator was involved with a task associated with the operation of filter press A. Such tasks would either be in the form of "active" or "passive" operator participation. The former would include duties in which the operator was actually controlling the operation of the filter press (e.g., opening or closing valves, turning on or off the sludge feed pump, removing cake from the filter cloth, etc.). The passive role occurred whenever the operator observed or monitored the progress of the filtration operation, but no physical contact with the equipment occurred.

With one exception, all of the exposures occurred while the operator was inside the filter press room. The one area outside of the filter press room in which the operator could accrue exposures was the region from the east doorway of the room to, and including, the location of the sludge feed pump and its associated valves. The periods of time that did not constitute an exposure for the operator under this study were whenever the operator left the filtration area and the filtration operation (personnel air samples were off at these times).

MASS BALANCE MEASUREMENTS

General

In general, the mass balance of the batch filter press operation at Plant 50 can be expressed as follows:

sludge feed = filter cake + filtrate + spills + residue on filter cloths (1)

When applying the above equation to the target chemical (total copper), the mass of total copper in the filter cake represents the chemical "product" and the masses of total copper in the filtrate and spills represent the chemical releases. The masses of total copper in the sludge feed and filtrate were estimated through volumetric measurements and laboratory analyses of samples. The mass of total copper in the filter cake were estimated by weight measurements and again laboratory analyses. While spills were observed, the mass of total copper in those spills could not be directly measured.

Sludge and Filtrate Volumetric Measurements

The most feasible in situ method to document the quantity of sludge feed processed and filtrate produced was to measure the depths of those materials inside their respective storage tanks. Since the cross-sectional areas of these tanks were known, differences in the depths of the stored sludge and filtrate yielded known volumes of the materials. The volumetric calculations and the analytical results of the samples enabled the computation of sludge and filtrate masses.

A tape measure was used to measure the distance from the top of the tank to the material's surface at the start and completion of the sludge filtering stage. Interim depth measurements were also periodically obtained. Based upon statements by the press operators, all of the pipes between the tanks and the filter press were assumed to be filled at the time of all measurements (thus, eliminating consideration of their volumes in the calculations).

Filter Cake Weight Measurements

All of the chamber plates on the filter press were identical. Thus, the 23 plates formed 22 identically-sized chambers to retain filter cake. Inspection of the chambers as the plates separated during the filter cake removal stage indicated that all chambers were completely filled with densely packed filter cake. Consequently, it was assumed that measurements of the filter cake contained within one chamber would be reasonably representative of the cake inside the other 21 chambers.

A different chamber was selected for sampling and weighing during each cycle. The filter cake from the randomly selected chamber was collected by spreading a sheet of plastic under the affected set of chamber plates before the plates were separated. The plastic sheet remained in place until the pair of filter cloths in the chamber were cleaned. The filter cake on the plastic sheet was promptly weighed on a balance (Homs Beam Scale, Model 305ADP, serial number 10233, one-ounce graduated divisions). The weighing results from the one chamber were then multiplied by 22 to compute the total filter cake mass for that cycle.

Spills and Leaks

Observations of all leaks or spills during the filtration operation were documented by the survey crew members. The documentation of such events included the following information: type of material, quantity, location, and time of occurrence.

SAMPLE COLLECTION

General

The sampling requirements to document worker exposures and chemical releases from the filter press operation included bulk, air, and wipe samples. Table 1 identifies the types of samples collected during each stage of the filtration operation.

TABLE 1. SAMPLES COLLECTED DURING THE STAGES OF THE FILTRATION OPERATION

	Stage		
Samples Collected	Sludge Filtering	Cake Drying	Cake Removal
Bulk			
Sludge Feed	Yes	N/A	N/A
Filtrate	Yes	N/A	N/A
Filter Cake	N/A	N/A	Yes
Air			
Background	Composite during all 3 stages		
Area	No	Yes	Yes
Personnel	Yes	No	Yes
Wipe	No	Yes	Yes

N/A = Not Applicable

Bulk Samples

As described above, the volumes of sludge feed and filtrate associated with the filtration operations were measured as well as the weights of filter cake produced by the filter press. The bulk samples of the sludge feed were grabbed from the sludge storage tank immediately prior to the start of the sludge filtering stage. The samples were collected at the center of the mixing zone. The samples were split and placed into glass and plastic containers for copper and total residue analyses, respectively. The samples for soluble copper analyses were obtained by filtering sludge samples on site through 0.45 micron filters. All of the samples for both total and soluble copper analyses were preserved with nitric acid.[3]

The bulk samples of filtrate were collected at the outlet of the collection trough discharge pipe. At a given time in the sludge filtering stage (every 10 minutes during the first filtration operation and every 5 minutes during the second and third filtration operations), approximately 750 mL of the filtrate flowing out of the discharge pipe were collected and placed into a storage container. At the conclusion of the sludge filtering stage, this composite sample was mixed and then poured into the individual containers for copper and total residue analyses. A composite sample was obtained for each of the three filtration cycles studied. The methods for preparing samples for soluble copper analyses and preserving the copper samples were identical to those used for the sludge feed samples. Small fragments of filter cake (a total of about 500 g) from the chosen chamber were selected and placed into two separate containers for total residue and copper analyses.

Air Samples

Three different types of air samples were collected to ascertain the airborne concentrations of copper associated with the filtration operation: background, area, and personnel air samples. All of the samples were collected by using battery-operated pumps, duPont P4LCs, to pull air through 0.8 micron mixed-cellulose ester membrane filters. Each pump was calibrated prior to and after its designated sampling period so that the initial and final air flow rates through the filter were known. A Buck Calibrator, serial number M-6874, was utilized as the primary standard for calibrating the air pumps.

The background air samples were collected at those locations where air either entered into or exited from the filter press room (i.e., the east and west doorways and the exhaust fan). The sampling period began just prior to the start of the sludge filtering stage and ended with the conclusion of the cake removal stage. Therefore, these air samples gave an indication of the airborne copper concentrations that were entering into or exiting from the filter press room during the entire filtration operation. (The application of the background air samples is discussed in the section on results.) More specifically, since the east doorway was the primary source for air entering into the filter press room, the air samples at this location would reveal the airborne concentrations of copper in the room which were not attributable to the filtration operation. The air samples taken at the west doorway and the exhaust fan, which were the two exits for air leaving the room, would yield the concentrations of copper being added to the air as a result of the filtration operations neglecting losses due to particle settling or increases from reentrainment. Figures 11 and 12 illustrate the positions of the three background air samples. These positions were constant through the four cycles of the filtration operation.

Additional area air samples inside the filter press room measured the airborne copper concentrations that existed at locations during specific stages of the filtration operation. Area air samples were positioned at the north and south ends of the filtrate collection trough during the cake drying and cake removal stages. The third area sample location was in front of the control panel for filter press B during the cake drying stage. These area air samples were positioned at a height above the floor comparable to an operator's breathing zone (i.e., 1.5 meters) and at a location that would not interfere with the operators' activities. The locations of the area air samples are also illustrated on Figures 11 and 12 and were identical for all four cycles of the filtration operation.

Since operators did not remain inside the room for more than 3 minutes during the cake drying stage, the area samples were the only feasible way to document the airborne copper concentrations present in the room during this stage and thus, were used to estimate worker exposure. (For the anticipated airborne total copper concentrations inside the room, sampling times of less than 15 minutes were not expected to yield detectable quantities of copper.)

Since it was believed that the cake removal stage would likely produce the highest levels of airborne copper, area samples placed at either end of the collection trough during this stage were used to provide useful data to supplement the exposures recorded by the operators' personal samples (e.g., the distribution of airborne copper particulates beyond the breathing zone of the operator).

The personnel air samples measured the operators' exposures to airborne copper during the sludge filtering and cake removal

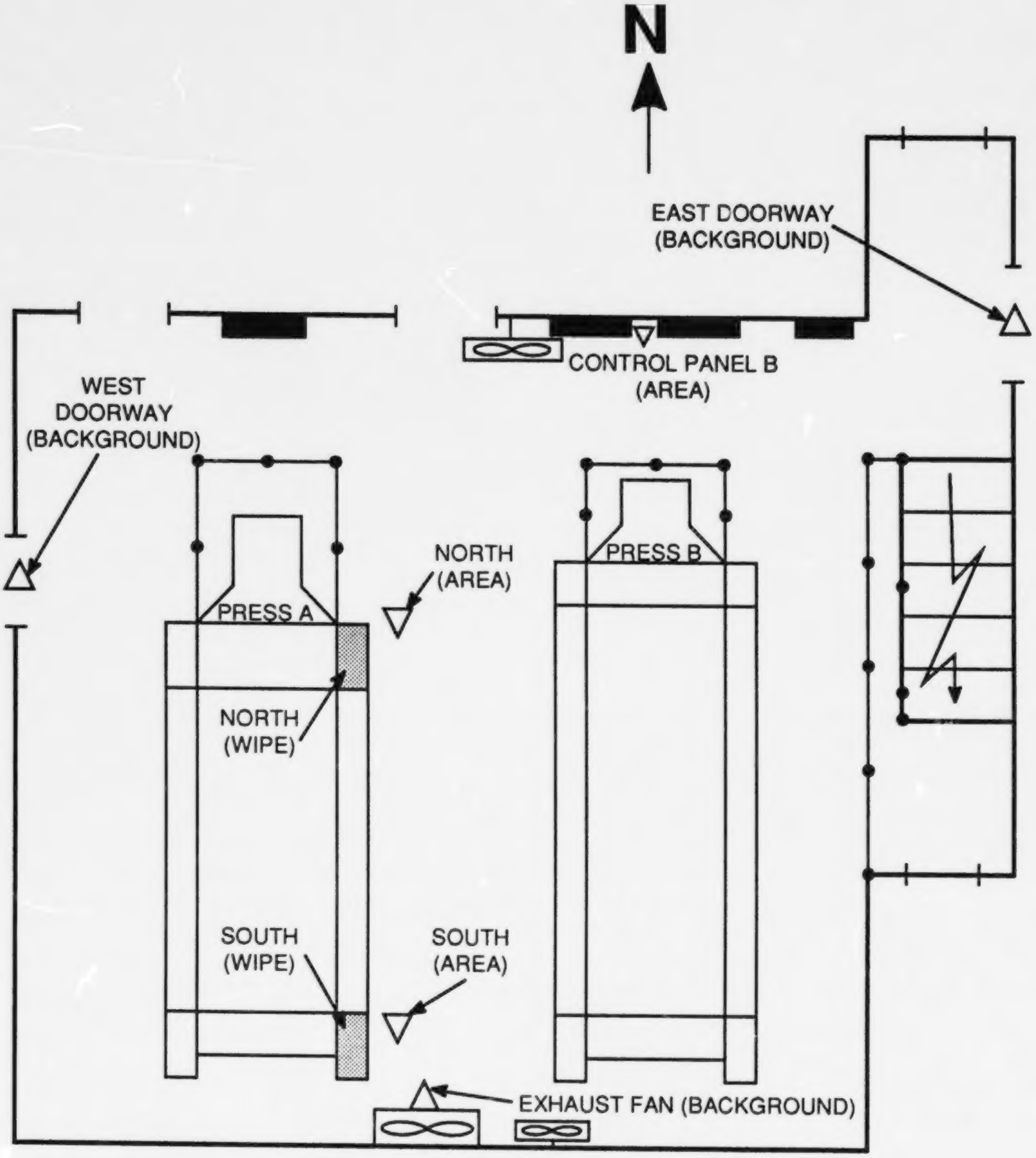

N
EAST DOORWAY
(BACKGROUND)
CONTROL PANEL B
(AREA)
WEST
DOORWAY
(BACKGROUND)
NORTH
(AREA)
PRESS A
PRESS B
NORTH
(WIPE)
SOUTH
(WIPE)
SOUTH
(AREA)
EXHAUST FAN (BACKGROUND)

Figure 11. Plan View of Area and Background Air Samples.
(Samples Denoted by △)

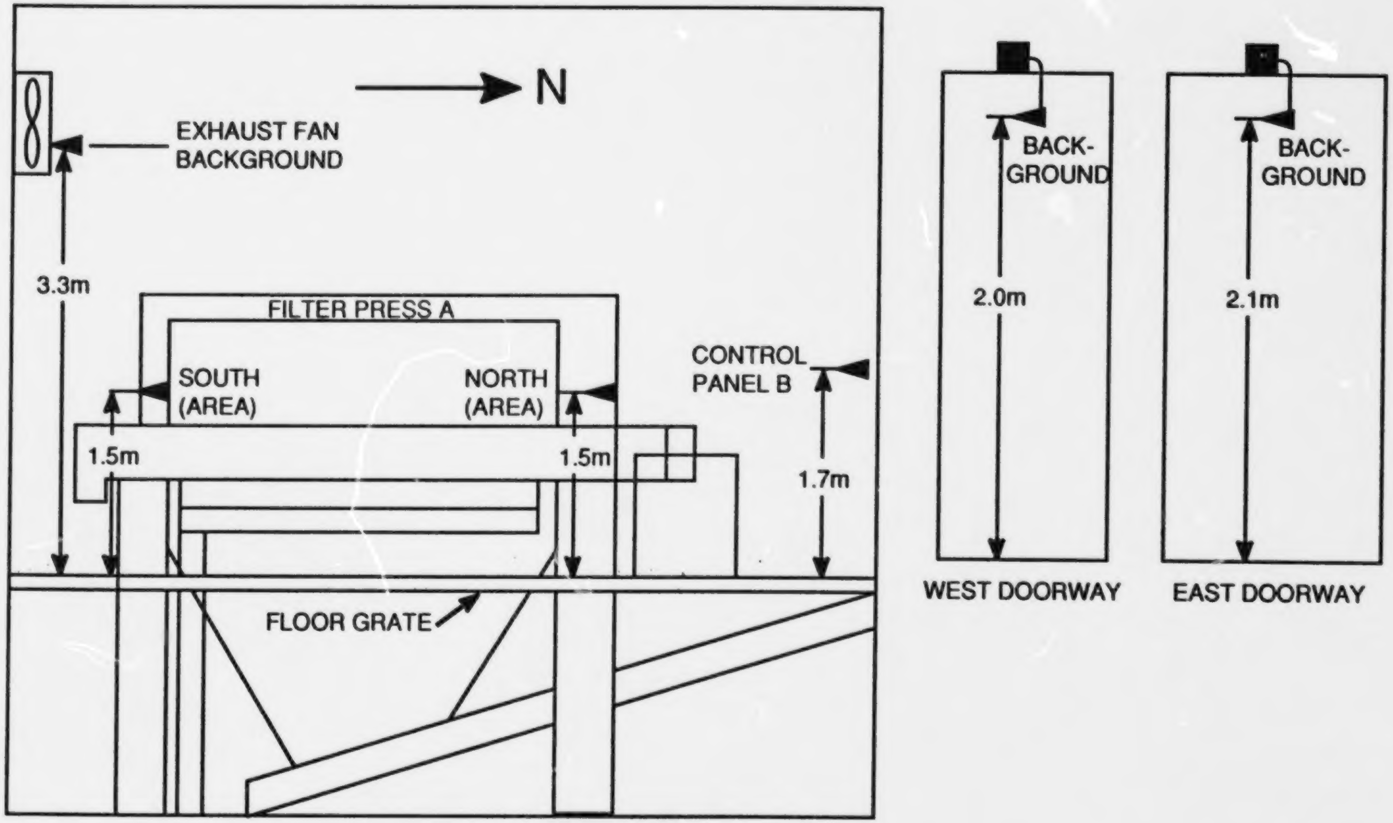

N
EXHAUST FAN
BACKGROUND
3.3m
FILTER PRESS A
SOUTH
(AREA)
NORTH
(AREA)
1.5m
1.5m
CONTROL
PANEL B
1.7m
FLOOR GRATE
BACK-
GROUND
2.0m
WEST DOORWAY
BACK-
GROUND
2.1m
EAST DOORWAY

Figure 12. Cross-Sectional View of Area and Background Samples.
(Samples Denoted by ◀)

stages. The sample collection cassette was attached to the operator's shirt collar (right or left side, depending on whether the operator was right-handed or left-handed, respectively) to monitor the airborne copper concentrations that were present within the breathing zone.

Wipe Samples

To estimate the rate at which copper was deposited on surfaces within the filter press room, wipe samples were collected on two flat, horizontal areas of the filter press. These two areas, one each at the north and south ends of the filter press, were chosen because:

1. They were the largest horizontal areas of the press near the filter cloths and filtrate trough that would be likely to collect aerosols emitted from those two sources.
2. They were in close proximity to the area samplers (see Figure 11) which could be used for correlating the mass of deposited aerosols with the airborne concentrations.
3. Their rectangular configuration simplified surface area calculations.

The wipe sample area at the north end of the filter press was 630 cm^2 in size, and the south wipe sample area contained 550 cm^2. Prior to the initiation of the cake drying and cake removal stages of the second and third filtration operations, the two areas were washed with deionized water and dried with a cloth towel. A cellulose filter paper was then rubbed over the entire surface of the two areas as a blank sample. Following the conclusion of each of the two stages, individual filters were rubbed over each area. The wipe samples were placed in individual glass jars.[4]

SEALING POINTS

The sealing points associated with the filter press system were inventoried and categorized to include where applicable their type, number, form of seal or packing, manufacturer, model number, size, and description of use. A total of 37 sealing points (2 pumps, 8 valves, 26 open-ended lines, and 1 connection) were associated with the process of filtering general sludge through filter press A.

During the sludge filtering stage of the fourth filtration operation, direct-reading instruments were used to detect fugitive emissions from the sealing points. Copper emissions from the sealing points would be in the form of mists produced from the liquid-air mixtures within the filter press system (i.e., it is not reasonable to assume that the copper would exert a detectable vapor pressure in this situation). A Real-Time Aerosol Monitor, Model RAM-1, serial number 1210, manufactured by GCA Corporation was utilized to detect such aerosol emissions from the sealing points. The RAM-1 was calibrated prior to and after the survey using its internal reference source (Arizona Road Dust), and adjusted to background levels.

Other chemicals in the liquid-air mixtures could possess detectable vapor pressures. Of secondary interest (i.e., not related to the target chemical) was the presence of any miscellaneous vapor emissions from this set of sealing points. A Trace Gas Analyzer, Model IS101, serial number 711007, manufactured by HNU Systems was utilized to detect vapor emissions. The analyzer was equipped with an 11.7 eV probe, serial number M1191, and calibrated prior to and after the survey using the calibration gas supplied by the manufacturer.

ANALYTICAL METHODS

Copper analyses of the sludge, filter cake, wipe, and filtrate samples were accomplished by direct aspiration flame atomic absorption spectrophotometry, using Method 220.1 of Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020. Total residue analyses of the samples were accomplished in accordance with Method 160.3 of the same reference.[3] The copper analyses of the air samples were performed in accordance with NIOSH Method 7029.[5]

QUALITY ASSURANCE PROCEDURES

Prior to the initiation of the field study, a QA Sampling and Analysis Plan was developed to identify the necessary procedures and methods for successful achievement of the study's objectives. As a result, the following quality assurance procedures were implemented during the study:

1. Ten percent of the samples taken for each type were collocated samples. Collocated samples were collected by placing a second air sampler adjacent to the "primary" air sampler; or, collection of a second bulk sample at the same time and location of the "primary" bulk sample. In addition, field blanks for each sample type were included.

2. In the laboratory, ten percent of the samples collected (including collocated samples) were analyzed in duplicate, and ten percent of the samples analyzed for copper were also spiked with known copper concentrations. Laboratory (method) blanks as well as the field blanks were analyzed.

3. The measure of analytical accuracy was the percent recovery of the spiked samples expressed as:

$$\text{Percent Recovery for analytical accuracy} = \frac{\text{measured spike concentration}}{\text{true spike concentration}} \times 100\,\% \qquad (2)$$

4. The analytical precision was the percent difference between the original and duplicate analyses expressed as:

$$\text{Percent Difference for analytical precision} = \frac{(\text{original result} - \text{duplicate result})}{(\text{original} + \text{duplicate results})/2} \times 100\% \qquad (3)$$

5. Sampling precision was measured with the collocated samples and would be calculated as:

$$\text{Percent Difference for sampling precision} = \frac{(\text{primary result} - \text{collocated result})}{(\text{primary} + \text{collocated results})/2} \times 100\% \qquad (4)$$

6. A Field Work Auditor visited the site during the field data collection activities. An audit was performed to verify that the field sampling procedures were being conducted in accordance with the QA Sampling and Analysis Plan.

SECTION 7

RESULTS

VENTILATION

The smoke tracer observations revealed that air entered the filter press room via the east doorway (from the waste treatment area). Air exited the filter press room via the west doorway (to the concentrated waste acid treatment room) and the exhaust fan in the south wall of the filter press room. The metal grating that formed the floor for the upper level of the filter press room allowed air to freely exchange between the upper and lower levels. This general air flow pattern was found to be fairly constant during the in-plant assessment study based upon observations of the smoke tracers during each of the four filtration operations. The air flow pattern remained relatively uniform for three primary reasons:

1. The two doors in the north wall of the filter press room were closed during the study, thus eliminating natural ventilation effects from the open-air trailer shed.

2. The exhaust fan in the filter press room and a similar exhaust fan in the concentrated waste acid treatment room combined to exert a steady demand upon the air inside the filter press room.

3. A steady source of air was supplied to the filter press room by the waste treatment area via natural convection. The waste treatment area receives its air from a combination of mechanical and natural ventilation sources. Since the volume of the waste treatment area is approximately twenty times greater than the volume of the filter press room, the waste treatment area dampens short-term fluctuations in the air before it enters the filter press room.

The air velocity measurements at the doorways and the exhaust fan are presented in Table 2. The average air flow rates at these locations are provided in Table 3. In Table 3, the combined air flow rates for the exhaust fan and the west doorway have also been given to permit a direct comparison of the air flow rates into and from the filter press room.

TABLE 2. AIR VELOCITY MEASUREMENTS AT SUPPLY AND EXHAUST OPENINGS

Opening and its Face Area	Cycle	Average Air Velocity, Standard Meters Per Second
West Doorway	1	0.60
	2	0.69
($1.60\ m^2$)	3	0.74
	4	0.63
Exhaust Fan	1	2.9
	2	3.0
($0.71\ m^2$)	3	3.0
	4	2.8
East Doorway	1	1.05
	2	1.15
($2.13\ m^2$)	3	1.20
	4	1.10

TABLE 3. GENERAL AIR FLOW RATES INTO/FROM FILTER PRESS ROOM

	Air Flow Rates in Standard Cubic Meters Per Second			
Filtration Operation Cycle	Exhaust through West Doorway	Exhaust Fan *	Total Combined Exhaust	Supply through East Doorway
1	1.0	1.6	2.6	2.2
2	1.1	1.7	2.8	2.4
3	1.2	1.7	2.9	2.6
4	1.0	1.6	2.6	2.3
Average	1.1	1.6	2.7	2.4

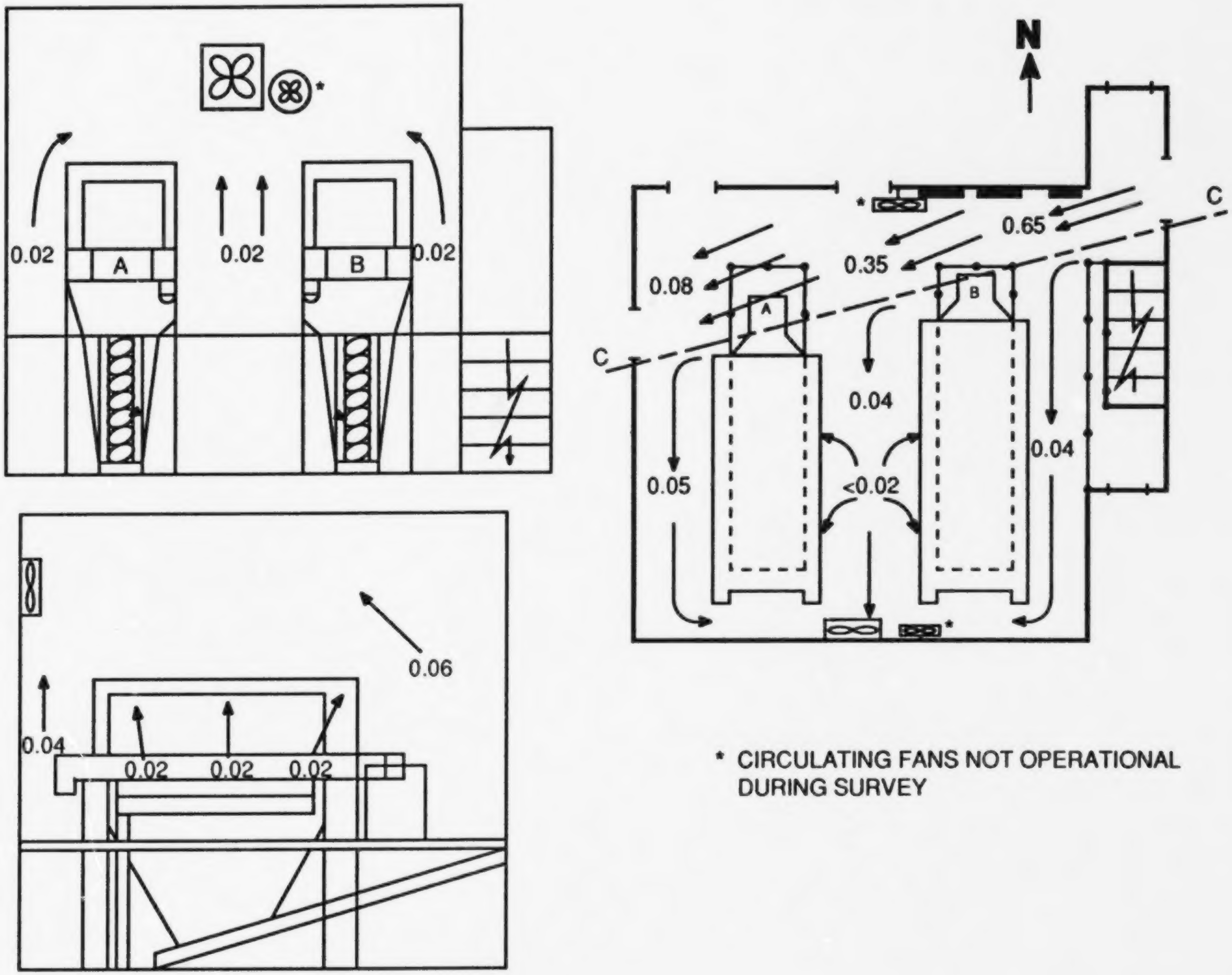
* Using a reduction factor of 0.78 due to bar grill cover.

As can be seen from the data, the air being exhausted through the fan and the west doorway is consistently slightly greater than the air flowing into the east doorway. While some of this difference could be attributable to errors in the ventilation measurements, it is assumed that most of the difference is a result of air infiltrating into the filter press room from locations other than the east doorway. In the lower level of the filter press room, unsealed penetrations in the walls for pipes and especially the two screw conveyors could be the primary sources of this minor air infiltration. On the average, 89 percent (based on air exhausted from the filter press room) of the air entering the room flows through the east doorway and the remaining 11 percent enters via the unsealed wall penetrations in the lower level.

If the air inside the filter press room was uniformly mixed, the average exhaust air flow rate of 2.7 m^3/s provided 28 exchanges of room air per hour (gross room volume, including lower level, equal to 352 m^3). Not surprisingly, the smoke cloud observations indicated that the distribution of air within the filter press room was not uniform. Sketches of the major air patterns in the filter press room are presented in Figure 13. This air mixing information was compiled from the smoke tube studies conducted during the four filtration operations and it can be summarized as follows:

1. A significant portion of the air that entered the room via the east doorway flowed directly towards the west doorway. As the air current moved from the east to the west doorway, there appeared to be very little air from other regions of the room becoming entrained into the air current. Hence, the portion of the room in front of the filter presses (north of line CC in Figure 13) possessed good air movement and the quality of this air was relatively unaffected by the filtration unit operation. Unfortunately, the operators spent the vast majority of their time in the other portion of the room (south of line CC in Figure 13). In effect, the air flowing through the west doorway (which comprised 41 percent of all the air being exhausted from the room) was not available to reduce the concentration of airborne contaminants in the operators' breathing zones.

2. All along the main "east-to-west current," streams of air broke off and flowed into the other areas of the room. The most noticeable of these offshoots were along the east and west walls where the air streams gradually gained altitude as they traveled along the walls. By the time they approached the south wall, the air streams were arcing upward toward the exhaust fan.


N
C
C
0.65
0.35
0.08
A
B
0.04
0.04
0.05
<0.02
*
*
0.02
0.02
0.02
A
B
*
0.06
0.04
0.02
0.02
0.02

* CIRCULATING FANS NOT OPERATIONAL
DURING SURVEY

Figure 13. Air Velocity and Movement Patterns.
(Measurements in Meters Per Second)

Elsewhere along the front of the room, the air streams that broke off from the main current rose very quickly as they drifted towards the exhaust fan.

3. At the breathing zone level in the area between the two filter presses, the movement of air was quite restrained. There was some lateral movement of air but the velocities were minimal until the air passed over the presses. Smoke released at the edge of the filtrate collection troughs rose very slowly with the rate of horizontal dispersion being even slower.

In summary, the ventilation measurements showed that the movement of air through the filter press room was relatively constant at a given location throughout the study, but the air velocities varied from location to location. Therefore, if the air sampling results show a wide variety of concentrations occurring at a given location during the study, changes in ventilation would not be the primary cause for this occurrence. Secondly, while the gross ventilation rate for the entire filter press room was quite impressive, the area of the room most frequently occupied by the workers was also the area that received the least air circulation.

WORKER SCENARIOS

General

Table 4 shows the schedule of the work shifts for Plant 50, the filter press operators monitored during the field sampling study and their years of experience operating the filter presses at Plant 50, and the times that a filtration operation was monitored. The operators were the workers routinely assigned to the filter presses and would have been operating the filter presses during those shifts even if the field sampling study had not occurred. There was no strategy used to select a specific filtration operation other than to insure that each of the three work shifts was represented.

Personal Protective Equipment

Plant 50's safety regulations require the filter press operators to wear chemical safety goggles while inside the filter press room and hearing protection devices during the cake drying stage. All three operators complied with these regulations. Operators A-1 and C-1 always wore cotton work gloves. In addition, Operator C-1 wore a disposable, half-face dust respirator during the cake removal stage. Operators B-1 and C-1 wore short-sleeve shirts while Operator A-1 wore a 3/4-length sleeve shirt.

TABLE 4. WORK SHIFTS AND OPERATORS MONITORED DURING FIELD SAMPLING STUDY

Plant 50's Work Shift Schedule (hours)	Filter Press Operator and Years of Experience	Time Period that the Filtration Operation was Studied (hours)
0700 - 1500	A-1, 8.5 years	1045 - 1330
1500 - 2300	B-1, 9 years	1755 - 2000
2300 - 0700	C-1, 2 years	2355 - 0155
0700 - 1500	A-1, 8.5 years	1150 - 1450

Sludge Filtering Stage

In Appendix A, Tables A-1 through A-4 present the work scenarios of the operators during the four filtration operations and Figures A-3 through A-6 illustrate their respective work paths. Operator A-1, monitored during the first and fourth cycle, conducted the longest sludge filtering stages (57 and 40 minutes, respectively). It is uncertain whether these extended filtering periods represented a concerted effort by this operator to obtain a maximum sludge load on each filtration cycle, or just a matter of personal preference. Operators B-1 and C-1 accomplished their sludge filtering periods in 26 and 32 minutes, respectively.

While the durations of the sludge filtering periods varied among the operators, certain aspects of this stage were consistent regardless of the employee operating the filter press. As can be seen in Table 5, the exposure durations for starting the press, inspecting it for leaks, and stopping the press were nearly identical for all three operators. The operating procedures for the filter press involve specific, straightforward items such as opening/closing a set of valves and turning the sludge feed pump on/off.

The differences in the exposure durations occur primarily due to the periods of time that the operator remained inside the filter press room to observe and monitor the filtration operation. At the start of the filtering stage, the operator must visually check the press to insure that it closed properly and no major leaks were occurring. Although the operator may

TABLE 5. DURATIONS OF OPERATOR EXPOSURES DURING SLUDGE FILTERING STAGE

Activity Causing Exposure	Duration of Operator Exposures in Minutes CYCLE, OPERATOR 1,A-1	2,B-1	3,C-1	4,A-1	Average
Start-up, Inspection and Shut-down	10	13	11	9	11
Observing and Monitoring Filtration	47	13	21	31	28
TOTAL	57	26	32	40	39

need to periodically monitor the progress of the filtering process by observing the flow of filtrate from the spigots, these experienced operators were knowledgeable about the times needed to routinely filter the various sludges and predicted the time for stopping the process fairly accurately without examining the filtrate. Observations of these same operators at other times indicated that they did not normally stand and watch the press during the entire filtering stage. Usually, once the operator started the filter press and was assured that the press was performing correctly with no leaks, the operator would accomplish other duties in the waste treatment area or remove the filter cake from the other press until it was time to stop the filtering operation. During this study, no other activities were conducted in the filtration room.

Since it was essential that Press A be the only source of the target chemical in the filter press room, the operator could not conduct any operations with Press B during the field sampling activities. Nevertheless, the operators elected to remain in the filter press room during the entire filtering stage even though there was no operational requirement mandating their presence. The subsequent result of their decision was that their exposure durations during the sludge filtering stages were probably longer than their normal routine. It would be reasonable to estimate that their normal exposure durations during this stage typically would be closer to 11 minutes for a single filter press (average of the times for start-up, inspection, and shut-down) rather than the 39 minutes averaged by the operators in this study.

The operators did not physically contact the feed or filtrate during the sludge filtering stage. The open construction of the filter press enabled an operator to stand at a distance from the press and quickly make a visual inspection for leaks or other malfunctions. Aside from the start-up and shut-down tasks, the physical activities of the operators were limited to standing and walking. Although there were isolated exceptions, the operators typically stood at a distance of 0.75 to 1.6 meters from the side of the press to monitor the filtration process. The filtrate flowed with little force from the spigots into the collection troughs and there was no visible evidence that the filtrate splashed out of the trough.

In a few instances, an operator did move closer to the press or take a body position other than standing. These exceptions were as follows:

1. Operator B-1 did stand 0.25 meters from the press to observe the filtrate beginning to flow out of the spigots (event 4 in Table A-2). The operator stayed at this location for 30 seconds.

2. Operator C-1 stood adjacent to the side of the press to watch the press close (event 3 in Table A-3). However, since this occurred before the sludge feed pump was turned on, no filtrate was present.

3. Operator C-1 crouched into a squatting position for 2 minutes at a distance of 0.9 meters from the press (event 9 in Table A-3). This was accomplished to point out to the Field Auditor a leak that was dripping from the center of a press frame into the screw conveyor. This action lowered the operator's breathing zone to a height comparable with the filtrate collection trough.

4. Operator C-1 stood adjacent to the press for 4 minutes to discuss the filter press operation with the Field Auditor (event 15 in Table A-3).

5. Operator A-1 during the fourth sludge filtering stage bent over at the waist during a discussion of filtrate spigots with the Project Manager (event 5 in Table A-4). This position lowered the operator's breathing zone to a height comparable with the filtrate collection trough and reduced the distance to the trough by roughly 0.5 meters. This position was retained for 1 minute.

It is interesting to note that these last three exceptions occurred in the midst of discussions with members of the survey team. It is doubtful that they would have occurred had the survey team not been present.

Aside from the variations in the exposure durations, probably the most noticeable difference among the operators was their "mobility" during the sludge filtering stage. Examination of the work scenarios and work path charts reveals that Operators B-1 and C-1 moved around the filter press room more frequently in shorter periods of time than did Operator A-1. While Operator A-1 tended to remain at a general location for long periods of time (up to 34 minutes) to observe the filtration process, Operators B-1 and C-1 never stayed at a location for more than 13 and 5 minutes, respectively.

In summary, the worker scenarios illustrate that the two parameters in the sludge filtering stage that varied the most due to the operator's techniques or preferences were: (1) overall duration and (2) the operator's mobility in the room. However, the two parameters which appeared to be the most immune to the operator's influence were: (1) the actions needed to actually control the filtering process and (2) the absence of contact with the material being filtered or lack of need to be even in close proximity to the filter press. Although the differing mobility of the operators and their variable exposure durations may qualify the sludge filtering stage as a scenario that is greatly influenced by the operators, the effects of these variables are mitigated to a large degree by the restricted involvement of the operators during this stage and the automated nature of mechanical filtration. There was no evidence to suggest that during routine sludge filtering stages the operators could increase or decrease their exposures through their own techniques or actions.

Filter Cake Drying Stage

While the sludge filtering stage exhibited some variability among the operators, the filter cake drying stage possessed practically no variability. The operators accomplished the operational procedures in the same manner and, subsequently, incurred identical exposure durations. The uniformity in the scenarios is a result of two factors: (1) the simple operating procedures required to start and stop the cake drying stage and (2) the operator's preference to remain outside of the filter press room while the compressed air is being blown through the filter cake. Although the drying of this particular batch of sludge did not appear to generate a great quantity of aerosol into the room, the operators stated that some sludges, particularly the waste concentrated acid, do produce sizable amounts of aerosols. Therefore, the operators generally vacate the room as a routine practice regardless of the sludge being processed. In Appendix A, Table A-5 presents the work scenario for the cake drying stage and the work paths corresponding to this scenario are illustrated on Figure A-7. The valve (V14) at the rear of the filter press controls the flow of compressed air through the filter cake. Therefore, during the initial 1.5 minutes of the drying stage (events 1 through 3 in Table A-5) and the final 0.5 minutes of the stage (events 7 and 8 in Table A-5), compressed air is not being blown through the filter cake. The major aspects of the filter cake drying stage can be summarized as follows:

1. The average total duration of the stage during the four iterations was 57 minutes.
2. Compressed air was blown through the filter cake for an average of 55 minutes.
3. Each operator was inside the filter press room for 3 minutes to start and stop the compressed air.
4. The time during which each operator was inside the filter press room while compressed air was being blown through the filter cake was only 1 minute.
5. The only time variable occurred when the operators were outside of the filter press room while compressed air was blowing through the filter cake.

During the one-minute period the operators were inside the filter press room with compressed air blowing through the filter cake, one aspect of the operators' technique influenced exposure. When exiting the room after opening the air valve (V14) and when entering the room to close that air valve, all of the operators deliberately walked down the side of the filter press opposite from the filtrate collection trough. The fact that this path was not the shortest route between the east doorway and the air valve attests to the preference of the operators to avoid the aerosol under normal circumstances. If a situation dictated that an operator must walk past the trough while the compressed air was blowing, this action would increase the operator's exposure. However, as long as the operators continue to spend the majority of the time of the filter cake drying stage duration outside the filter press room, this stage has little bearing on their overall exposures.

Filter Cake Removal Stage

The final stage of the filtration operation, removal of filter cake from the recessed chamber plates, was found to be the work stage that demonstrated broad similarities and intricate differences among the procedural methods implemented by the operators. The similarities were caused by equipment limitations that restricted the operators' actions. However, sufficient opportunities existed for each operator to accomplish the basic tasks in slightly different manners. The filter cake removal stage unquestionably comprised the operators' greatest potential contact with the target chemical. The filtration of the feed sludge through the filter press yielded a dry (nonsticky), compact filter cake that could be crumbled into small fragments by moderate hand pressure. Observation of the process indicated that this stage would comprise the largest component of an operator's total exposure for the entire filtration operation. Therefore, even slight variations to the techniques used by the operators in this particular stage could affect their overall exposures for the filtration operation.

During the filter cake removal stage, there were three main tasks in which equipment capabilities/liabilities and operator methods could combine to produce variable exposures. These tasks were:

1. As the chamber plates separated, most of the filter cake (roughly estimated to be at least 75 percent) fell into the hopper beneath the filter press. The force of the cake striking the hopper created the potential for cake particles to become airborne. A horizontal cord that is along the side of the press controls the motor that powers the plate separation mechanism. The motor will only operate while a downward force is being steadily applied to the cord. Therefore, all of the operators stood within an arm's length of the filter press and used one hand to push down on the cord. This requirement to hold onto the cord meant that all of the operators were potentially exposed to the dust emissions from the hopper. However, each operator was able to adopt any position or movement (e.g., standing, kneeling, leaning backward, bending forward, facing any direction, etc.) as long as they were still able to grab the cord. Their choice of position could affect their exposures to the dust.

2. All operators used the same wooden pole (1.25 m in length and similar in appearance to a broom handle) to remove the remaining cake from the filter cloth. The operators first vigorously slapped the filter cloth with the pole to dislodge most of the cake, and used the end of the pole to scrape the final remnants of cake from the filter cloth. The physical length of the pole and this instrument's suitability or capability for the task it was being utilized to accomplish were the common denominators determining the operators' exposures. The force that an operator exerted on the pole while slapping the filter cloth, the degree of cleanliness that the operator attempted to achieve on the filter cloths, the fulcrum location on the pole (i.e., the place where the worker held the pole), and the body positions of the operator during the procedure were variable factors that could impact individual exposures.

3. The operators could perform their cleaning actions and drop filter cake into the hopper at a rate that was slightly faster than the conveyor could move the cake out of the hopper. Hence, the operators had to adjust their work rate to prevent overloading the conveyor. This precaution was achieved primarily by the operator subjectively evaluating the sound transmissions produced by the conveyor. If noises from the conveyor indicated overloaded equipment, then the operator would pause until the noises had dissipated before opening the next plate (about 30 to 60 seconds). Occasionally, the operator would also make a visual check of the conveyor. This was accomplished by walking to the northeast door of the room and viewing the conveyor through the glass window in the door. From this position, the operator could see whether the conveyor was properly transporting the filter cake towards the disposal trailers. While at the door, the operator would be approximately 4.5 meters from the position occupied while cleaning the chamber plates. This change in position would move the operator away from the immediate area of the filter press where greater filter cake dust concentrations existed. Consequently, the limitations of the screw conveyor in transporting the filter cake from the filter press to the disposal trailers impacted the duration of this stage and the operators' exposure. The degree of this impact, however, was influenced by the operator's decisions as to the time intervals between plate separation and the frequency and duration of trips to the door.

The exposure durations of the operator during the four filter cake removal stages are presented in Table 6. These time periods encompassed the separation of the 23 chamber plates, cleaning the filter cloths between those plates, and monitoring the performance of the screw conveyor. Observations by survey team members who had also previously visited Plant 50, as well as comments made by the plant's industrial hygienist, indicate that the exposure durations of the operators in this field sampling study were shorter than had been seen previously. This difference was attributed to the moderate ambient temperatures during the field sampling study that made the environment inside the filter press room nearly ideal for the workers. Since Plant 50 is in a geographical area subject to high ambient temperatures during a majority of the year and the filter press room is not air-conditioned, the temperatures inside the room are often very uncomfortable for the operators. Consequently, during most of the year, the operators accomplish the arduous cleaning tasks at a slower pace than they demonstrated during this survey. Hence, the exposure durations in Table 6 should be considered as, or near to, the minimum time periods required by the operators to complete the filter cake removal stage.

TABLE 6. DURATIONS OF OPERATOR EXPOSURES DURING FILTER CAKE REMOVAL STAGE

	Cycle 1	2	3	4	Average
Operator Exposure (Minutes)	20	16	18	15	17

Since the operators' exposures during this brief stage were viewed to be critically dependent upon the manner in which each operator cleaned the filter cloths, the survey team primarily devoted its time towards observing and documenting the details of those individual mannerisms. Therefore, a specific breakdown of the times and work paths of the operators was not formulated for this stage as in the other two stages. In Appendix A, a description of the general actions performed by the operators in removing the filter cake is presented in Table A-6, and illustrated on Figure A-8.

As was previously discussed, the manual process involved in removing the cake residue from the filter cloths gave the operators an opportunity to adopt individual techniques for accomplishing this task. While it was inevitable that each operator did not perform the process in an identical manner, careful observation of the operators at the plant and a thorough review of the videotapes revealed only one major difference among the operators' methods to remove the filter cake. Operator C-1 consistently positioned himself so that his breathing zone was much closer to the filter cloths during the removal stage than did the other operators. Operators A-1 and B-1 stepped back away from the filter press when pulling down on the cord to separate the plates while Operator C-1 was next to, and often leaning against, the side of the press when a load of filter cake was discharged from a chamber. Additionally, Operators A-1 and B-1 stood at a distance from the press and extended their arms outward to slap and scrape the filter cloths with the wooden pole. Conversely, Operator C-1 stayed immediately next to the press and often leaned over the side of the press as he cleaned the filter cloths. Illustrating the difference in distance caused by these two methods, the elbows of Operators A-1 and B-1 always remained outside the frame of the filter press while Operator C-1's elbows were bumping against the filter cloths which are at least 0.3 meters inside of the press frame. Photographs of the filtration equipment and the operators as they performed their tasks are presented in Appendix B.

SAMPLE ANALYSES

Bulk Samples

The analytical results of the bulk samples collected from the sludge feed, filtrate, and filter cake during the first three filtration cycles are presented in Table 7 and Figure 14. Although the analytical results will be used later in combination with the volumetric and gravimetric measurements to provide mass balance computations, some noteworthy observations can be made upon preliminary inspection of the data presented in Table 7 and Figure 14.

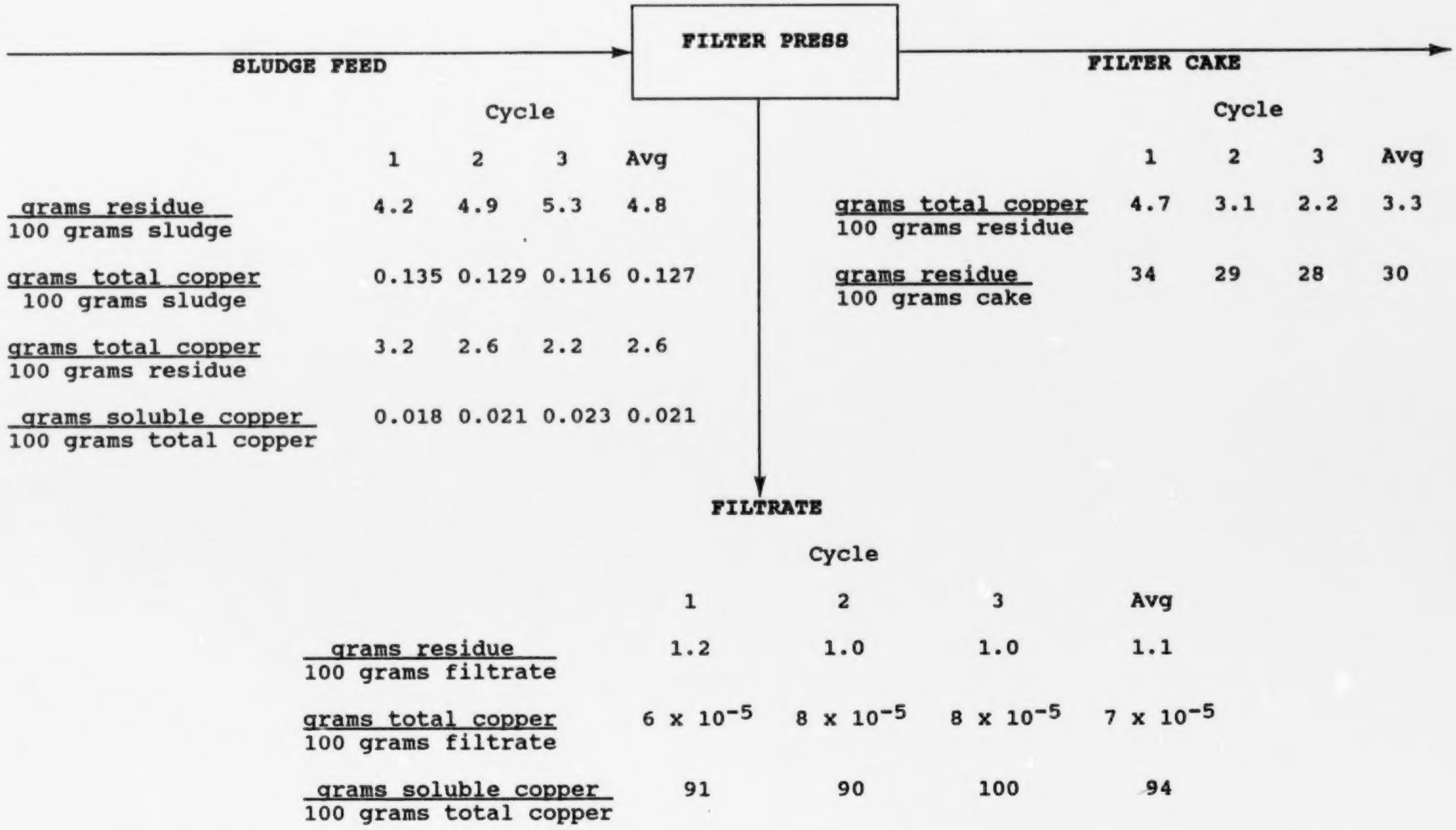
1. On the average, the concentration of total copper in the filter cake residue (3.3 percent) was greater than the concentration of total copper in the sludge feed residue (2.6 percent).
2. The differences between the total copper concentrations in the filter cake residue and the sludge feed residue decreased over the duration of the three cycles. It is hypothesized that initially Filter Press A could have contained residues of a concentrated copper sludge from previous filtration operations, and that this contamination was gradually purged from the filter press as the field studies progressed.
3. The average soluble copper concentration in the sludge feed was 0.02 percent of the average total copper concentration in the sludge feed (i.e., essentially all of the total copper in the sludge feed was in the insoluble form).
4. The average soluble copper concentration in the filtrate was 94 percent of the average total copper concentration in the filtrate (i.e., essentially all of the total copper in the filtrate was in the soluble form).
5. The concentration of soluble copper in the filtrate was greater than the concentration of soluble copper in the sludge feed.
6. The concentration of total copper in the filter cake decreased over the duration of the three cycles.

Air Samples (Worker Inhalation Exposure)

An index of the air samples collected during the four filtration operations is presented in Table 8. The index relates the sample numbers to the location of the samples and the stage(s) of the filtration operation that the samples

TABLE 7. ANALYTICAL RESULTS OF BULK SAMPLES COLLECTED FROM SLUDGE, FILTRATE, AND FILTER CAKE

	Cycle		
Parameter	1 Sample Result	2 Sample Result	3 Sample Result
	Sludge (Influent)		
Residue Concentration, mg/kg	42,350	53,430	52,840
(Duplicate Analysis)		52,230	
(Collocated Sample)		45,790	
Total Copper Concentration, mg/kg	1,350	1,320	1,160
(Duplicate Analysis)		1,270	
(Collocated Sample)		1,280	
Soluble Copper Concentration, mg/L	0.26	0.29	0.28
(Collocated Sample)		0.28	
Density, g/mL	1.05	1.05	1.04
(Duplicate Analysis)		1.05	
(Collocated Sample)		1.05	
	Filtrate (Effluent)		
Residue Concentration, mg/L	12,090	9,740	9,950
Total Copper Concentration, mg/L	0.593	0.822	0.781
Soluble Copper Concentration, mg/L	0.54	0.74	0.78
Density, g/mL	1.00	1.00	1.00
(Duplicate Analysis)	1.00		
	Filter Cake (Effluent)		
Residue Concentration, mg/kg	335,090	276,380	283,200
(Collocated Sample)		310,020	
Total Copper Concentration, mg/kg	16,200	8,660	6,230
(Duplicate Analysis)	15,300		
(Collocated Sample)		9,540	



SLUDGE FEED

	Cycle 1	Cycle 2	Cycle 3	Avg
$\frac{\text{grams residue}}{\text{100 grams sludge}}$	4.2	4.9	5.3	4.8
$\frac{\text{grams total copper}}{\text{100 grams sludge}}$	0.135	0.129	0.116	0.127
$\frac{\text{grams total copper}}{\text{100 grams residue}}$	3.2	2.6	2.2	2.6
$\frac{\text{grams soluble copper}}{\text{100 grams total copper}}$	0.018	0.021	0.023	0.021

FILTER CAKE

	Cycle 1	Cycle 2	Cycle 3	Avg
$\frac{\text{grams total copper}}{\text{100 grams residue}}$	4.7	3.1	2.2	3.3
$\frac{\text{grams residue}}{\text{100 grams cake}}$	34	29	28	30

FILTRATE

	Cycle 1	Cycle 2	Cycle 3	Avg
$\frac{\text{grams residue}}{\text{100 grams filtrate}}$	1.2	1.0	1.0	1.1
$\frac{\text{grams total copper}}{\text{100 grams filtrate}}$	6×10^{-5}	8×10^{-5}	8×10^{-5}	7×10^{-5}
$\frac{\text{grams soluble copper}}{\text{100 grams total copper}}$	91	90	100	94

Figure 14. Summary of sludge feed, filtrate, and filter cake analyses. (Values are calculated from Table 7 data.)

TABLE 8. INDEX OF AIR SAMPLES

Sample Number	Sample Location	Cycle	Filtration Stage
AB-F01R-C	West Doorway	1	All Stages
AB-F03R-C	Exhaust Fan	1	All Stages
AB-F02R-C	East Doorway	1	All Stages
AB-F04R-C	West Doorway	2	All Stages
AB-F05R-C	Exhaust Fan	2	All Stages
AB-F06R-C	East Doorway	2	All Stages
AB-F07R-C	West Doorway	3	All Stages
AB-F08R-C	Exhaust Fan	3	All Stages
AB-F09R-C	East Doorway	3	All Stages
AB-F22R-C	West Doorway	4	All Stages
AB-F23R-C	Exhaust Fan	4	All Stages
AB-F21R-C	East Doorway	4	All Stages
AE-F03R-C	Operator A-1	1	Sludge Filtering
AE-B03R-C	Control Panel, Press B	1	Cake Drying & Removal
AE-C01R-C	Operator A-1	1	Cake Removal
AE-F01R-C	Operator B-1	2	Sludge Filtering
AE-B01R-C	Control Panel, Press B	2	Cake Drying
AE-C02R-C	Operator B-1	2	Cake Removal
AE-F04R-C	Operator C-1	3	Sludge Filtering
AE-B04R-C	Control Panel, Press B	3	Cake Drying
AE-C03R-C	Operator C-1	3	Cake Removal
AE-F05R-C	Operator A-1	4	Sludge Filtering
AE-B02R-C	Control Panel, Press B	4	Cake Drying
AE-C04R-C	Operator A-1	4	Cake Removal
AR-B01R-C	North End, Press A	1	Cake Drying
AR-B02R-C	South End, Press A	1	Cake Drying
AR-C01R-C	North End, Press A	1	Cake Removal
AR-C02R-C	South End, Press A	1	Cake Removal
AR-B03R-C	North End, Press A	2	Cake Drying
AR-B04R-C	South End, Press A	2	Cake Drying
AR-C03R-C	North End, Press A	2	Cake Removal
AR-C04R-C	South End, Press A	2	Cake Removal
AR-B10R-C	North End, Press A	3	Cake Drying
AR-B05R-C	South End, Press A	3	Cake Drying
AR-C06R-C	North End, Press A	3	Cake Removal
AR-C05R-C	South End, Press A	3	Cake Removal
AR-B06R-C	North End, Press A	4	Cake Drying
AR-B07R-C	South End, Press A	4	Cake Drying
AR-C07R-C	North End, Press A	4	Cake Removal
AR-C08R-C	South End, Press A	4	Cake Removal

encompassed. Pertinent data contained in the coding of the sample numbers are as follows: AB - background air samples, AE - operator or work station samples, AR - area samples, FXXX - sludge filtering stage, BXXX - cake drying stage, and CXXX - cake removal stage. Table 9 presents the airborne copper concentrations together with the analytical and sampling data used to compute the concentrations.

Inspection of the airborne copper concentrations on the background air samples (the series of twelve sample numbers that contain "AB" as their first two letters) reveals that the samples collected during the first three filtration operations yielded similar results. Not only were the air concentrations of the same general magnitude, but the relationships among the three sampling locations were consistent during the first three cycles: the copper concentration in the air exiting the room via the west doorway was slightly less than the copper concentration in the air entering the room via the east doorway, and the copper concentration in the air exiting the room via the exhaust fan was slightly greater than the copper concentration found at the east doorway. The background air samples collected during the fourth filtration operation, particularly the one at the east doorway, were dissimilar to the results obtained during the prior cycles. The higher airborne copper concentration found at the east doorway (sample #AB-F21R-C) was not supported by any other area sample result obtained during the fourth cycle. One possible explanation for the elevated copper concentration at the east doorway during the fourth cycle was that the field team was performing a survey of the sealing points outside the east doorway during that cycle's sludge filtering stage. The movement of team members crawling around the various pipes may have caused settled particles from previous operations to be reentrained into the air entering the east doorway.

Due to the structure of the background air sample collection strategy, it is difficult to ascertain if the airborne copper that entered the filter press room via the east doorway remained airborne throughout the room and was detected by the other air samplers. The previously described poor ventilation mixing pattern inside the room could have caused some of the copper that entered from the east doorway to settle and not affect the other area and personnel air samples. The west doorway's lowered copper concentration in comparison to the east doorway's values could be indicative of such an occurrence. Certainly, the copper detected at the east doorway in the fourth cycle did not appear to reach the exhaust fan or the west doorway air samplers. To estimate the reasonable worst-case worker exposures and chemical releases that potentially occurred as a result of the filtration unit operation, the following assumption is made: the background copper concentrations did not contribute to the copper values

TABLE 9. AIR SAMPLING DATA AND ANALYTICAL RESULTS FOR COPPER

Sample No.	Sample Period, minutes	Average Air Flow Rate, Lpm	Copper on Sample Filter, μg	Copper Air Concentration, μg/m3
AB-F01R-C	176	4.02	0.670	0.95
AB-F03R-C	181	3.95	0.944	1.32
AB-F02R-C	181	4.07	0.826	1.12
AB-F04R-C	120	3.93	0.554	1.17
AB-F05R-C	120	3.85	0.769	1.66
AB-F06R-C	120	4.12	0.672	1.36
AB-F07R-C	124	4.01	0.668	1.34
AB-F08R-C	115	4.00	0.746	1.62
AB-F09R-C	126	4.04	0.692	1.36
AB-F22R-C	140	1.71	0.202	0.84
AB-F23R-C	173	1.67	0.198	0.69
AB-F21R-C	177	1.71	1.037	3.43
AE-F03R-C	69	3.96	1.037	3.8
AE-B03R-C	98	4.06	0.658	1.7
AE-C01R-C	20	3.89	2.047	26
AE-F01R-C	27	3.86	0.503	4.8
AE-B01R-C	65	4.13	0.495	1.8
AE-C02R-C	28	4.02	1.267	11
AE-F04R-C	38	3.95	0.579	3.9
AE-B04R-C	51	4.06	0.536	2.6
AE-C03R-C	18	3.88	8.757	130
AE-F05R-C	44	1.70	0.289	3.9
AE-B02R-C	58	1.68	0.078	0.8
AE-C04R-C	15	1.69	0.543	21
AR-B01R-C	62	3.97	0.490	2.0
AR-B02R-C	62	4.02	0.580	2.3
AR-C01R-C	20	3.92	0.441	5.6
AR-C02R-C	20	3.98	0.752	9.4
AR-B03R-C	65	4.03	0.422	1.6
AR-B04R-C	65	4.02	0.501	1.9
AR-C03R-C	23	3.99	0.635	6.9
AR-C04R-C	23	4.00	0.549	6.0
AR-B10R-C	54	3.96	1.022	4.8
AR-B05R-C	54	3.97	1.042	4.9
AR-C06R-C	17	3.93	1.052	16
AR-C05R-C	17	3.95	1.022	15
AR-B06R-C	58	1.65	0.092	1.0
AR-B07R-C	58	1.65	0.077	0.8
AR-C07R-C	15	1.60	<0.025	<1.0
AR-C08R-C	15	1.60	0.048	2.0

found on the other area and personnel air samples (i.e., all of the copper found on the samples is assumed to have originated from the filter press operation). This worst-case assumption is made since it is unknown whether the airborne copper entering the room from the east doorway (i.e., background concentration) reaches the worker due to ventilation patterns.

Multiplying the airborne copper concentrations found at the exhaust air openings by the respective air flow rates measured at the exhaust air openings (Table 3) yields the mass flow rates of copper out of the filter press room. These mass flow rates are presented in Table 10.

Again, assuming the worst case to be that the background air entering the room from the east doorway was not the source of the copper found at the west doorway and at the exhaust fan, then Table 10 shows that the filtration operation yielded an average copper mass flow rate of 3.37 $\mu g/s$ out of the room. With an average duration of 113 minutes (6,780 seconds) to complete the filtration operation, the filter press unit operation released a maximum of 23 milligrams of copper that became airborne and remained airborne until it was exhausted out of the filter press room. If this assumption is realistic, then the following calculation shows that with complete air mixing throughout the room, 23 milligrams of copper would represent an average copper concentration of 1.2 $\mu g/m^3$ in the room during the 113-minute (1.9 hours) period.

$$(23 \text{ mg copper})/(352 \text{ m}^3 \text{ of air} \times 28 \text{ air changes/hour} \times 1.9 \text{ hours})$$

$$= 1.2 \times 10^{-3} \text{ mg/m}^3 = 1.2 \ \mu\text{g/m}^3$$

TABLE 10. MASS FLOW RATES OF COPPER FROM FILTER PRESS ROOM

	Copper Mass Flow Rates in Micrograms Per Second		
	Exhaust Outlets		
Cycle	West Doorway	Exhaust Fan	Combined Exhaust
1	0.95	2.11	3.06
2	1.29	2.82	4.11
3	1.61	2.75	4.36
4	0.84	1.10	1.94
Average	1.17	2.20	3.37

As will be seen in the following discussions, this average copper concentration in the room is lower than the typical concentrations found on the area and personnel samples. However, since those samples were collected closer to the press, the previously described poor circulation of air in the vicinity of the press as well as particles settling out of the air stream would tend to make copper concentrations measured closer to the press higher than found at the exhaust air outlets.

Table 11 presents the airborne copper concentration found on the area samples at the north and south ends of the filter press and at the control panel for filter press B.

TABLE 11. AIRBORNE AREA COPPER CONCENTRATIONS INSIDE FILTER PRESS ROOM

	Airborne Copper Concentrations in Micrograms Per Cubic Meter				
	Cake Drying Stage		Cake Removal Stage		
Cycle	North	South	North	South	Filter Press B Control Panel
1	2.0	2.3	5.6	9.4	1.7
2	1.6	1.9	6.9	6.0	1.8
3	4.8	4.9	16	15	2.6
4	1.0	0.8	< 1.0	2.0	0.8
Average	2.4	2.5	7.4	8.1	1.7

An evaluation of the area air sample results yields the following observations:

1. As expected, the filter cake removal stage produced the highest airborne copper concentrations in the immediate vicinity of the filter press at a height above the floor comparable to the employees' breathing zones.

2. Blowing compressed air through the filter cake during the drying stage produced lower (compared to the cake removal stage) airborne copper concentrations at the breathing zone level near the filter press. Although a visible mist was evident immediately above the filtrate collection trough during the drying stage, it appeared that most of the mist quickly fell towards the floor

within a distance of 0.5 to 0.75 meters of the trough. Unlike the region of the floor next to the trough, no surfaces of the press above the trough appeared to become wetted by the mist. In addition, sample analyses showed that the filtrate contained little copper (see results in previous section). Consequently, the low copper concentrations at the breathing zone height during the cake drying stage were probably due to: (1) the limited ability of the stagnant air between the filter presses to transport the mist aerosol and/or (2) the low copper content in the mist aerosol.

3. The difference in the copper concentrations between the filter press and the control panel illustrates that complete mixing of the air did not exist inside the filter press room.

4. The highest copper concentrations at each location occurred during the third filtration operation.

The results of the personnel air samples showing the operators' inhalation exposures to airborne copper during the sludge filtering and cake removal stages are presented in Table 12. The area sample results at the control panel during the cake drying stage were used to approximate the exposures incurred by the operators for the 3 minutes that they were inside the room during that stage.

To compute the TWA exposures to copper that the operators incurred as a direct result of their involvement with the filtration operation, two factors must be considered along with the personnel air sample results. First, the true duration of the filtration operation includes not only the times an operator was inside the filter press room, but also the time during the cake drying stage in which the operator left the filter press unattended and accomplished other duties outside the filter press room. During that period of time, the operator could not incur any exposure to copper from the filter press and therefore the exposure is automatically zero. Second, it has been assumed that the background airborne copper did not affect the personnel samples, and the sample results were caused only by the filter press operations (i.e., reasonable worst case). The formula used

TABLE 12. OPERATORS' INHALATION EXPOSURES TO AIRBORNE COPPER IN MICROGRAMS PER CUBIC METER

Cycle, Operator	Sludge Filtering Stage Time (min.)	Sludge Filtering Stage Concentration (μg/m3)	Cake Drying Stage Time (min.)	Cake Drying Stage Concentration (μg/m3)	Cake Removal Stage Time (min.)	Cake Removal Stage Concentration (μg/m3)	Time-weighted Average (TWA) Exposure Concentration for Filtration Operation, μg/m3*
1, A-1	57	3.8	3	1.7	20	26	5.3 (141 min)
2, B-1	26	4.8	3	1.8	16	11	3.1 (98 min)
3, C-1	32	3.9	3	2.6	18	130	25 (99 min)
4, A-1	40	3.9	3	0.8	15	21	4.2 (113 min)
GEOMETRIC MEAN CONCENTRATION		4.1		1.6		30	6.4
90% CONFIDENCE INTERVAL		(3.7 to 4.6)		(1.0 to 2.6)		(10.2 to 88)	(2.5 to 16)
GEOMETRIC STD. DEVIATION		1.1		1.5		2.5	2.2

* The total time that the filtration operation encompassed is shown in the parentheses. The difference between the total time and the sum of the times in the three columns is the time during the cake drying stage when the operator was outside the filter press room (see Table A-5). Since the operator was not involved in the filtration operation during that time, the copper concentration for that exposure time was zero.

to calculate the operators' TWA exposures to copper for the filtration operation is as follows:

$$\text{TWA} = (t_f c_f + t_d c_d + t_o c_o + t_r c_r)/T \qquad (5)$$

where

T = total time of the filtration operation ($t_f + t_d + t_o + t_r$).
t_f = time of the sludge filtering stage
c_f = copper concentration detected by personnel sample on operator during sludge filtering stage
t_d = time that operator was inside filter press room during cake drying stage (3 minutes)
c_d = copper concentration detected by area sample at control panel used to approximate operators' exposure during cake drying stage
t_o = time that operator was outside filter press room during cake drying stage (Table A-5)
c_o = copper concentration received by operator while outside filter press room during cake drying stage (zero)
t_r = time of the cake removal stage
c_r = copper concentration detected by personnel sample on operator during cake removal stage

An evaluation of the data in Table 12 reveals the following information:

1. Operators A-1 and C-1 encountered similar airborne copper concentrations during the sludge filtering stages of the first, third, and fourth cycles. However, as detailed in the worker scenario results, these two operators exhibited completely different movement patterns in this stage (i.e., Operator A-1 tended to remain at a location for long periods of time (up to 34 minutes) while Operator C-1 never stayed at one location for more than 5 minutes). Although Operator B-1's movement pattern was between the two extremes of the other operators, Operator B-1 incurred a copper exposure that was greater than the other three exposures. Thus, there does not appear to be a correlation in the sludge filtering stage between a worker's movement and the resultant chemical exposure.

2. The average airborne copper concentration encountered by the operators during the sludge filtering stage (4.1 $\mu g/m^3$) was higher than the average concentration documented by the area samples at the filtrate collection troughs during the cake drying stage (2.4 $\mu g/m^3$; from Table 11, the average of the north and south samples). This was despite the following facts: (1) the area samples at the troughs in the cake drying

stage were positioned much closer to the filter press in comparison to the routes of the operators during the sludge filtering stage; and (2) compressed air was blowing filtrate out of the spigots during the cake drying stage while the sludge filtering operation did not have this forceful expulsion of filtrate.

3. As expected, the cake removal stage yielded the highest airborne copper concentrations in the breathing zones of the operators. On the average, 72 percent of the operators' TWA copper exposure for the entire filtration operation was incurred during this particular stage. The operators spent only 15 percent of their time in this stage.

4. Operators A-1 and B-1 had similar copper concentrations recorded in their breathing zones during their participation in the cake removal stage. However, the copper concentration detected in the breathing zone of operator C-1 (130 $\mu g/m^3$) was greater than the average value for the other two operators. This higher concentration for operator C-1 corresponds with the observance that operator C-1 leaned closer to the filter cloths to remove the filter cake than did the other operators. This higher copper concentration found in the breathing zone was also substantiated by the fact that the area samples collected while operator C-1 removed the filter cake contained the highest levels of copper found during any of the cake removal stages. In addition, a collocated sample on operator C-1 analyzed by a different laboratory showed 140 $\mu g/m^3$ of copper.

5. It should be remembered that the operators did spend brief periods of time away from the filter press to monitor the performance of the screw conveyor. While away from the filter press, the operators' breathing zone samples would have been encountering copper concentrations equal to or less than the results yielded by the area samples at the ends of the filter press. These area sample concentrations were much lower than the values found by the operators' breathing zone samples. Therefore, the airborne copper concentrations near the recessed plates at the center of the filter press had to be even higher than the concentrations shown by the breathing zone samples.

Wipe Samples

The results of the copper analyses on the wipe samples, corrected for the mass found on the blanks, are presented in Table 13. Generally, the results indicated that the amount of copper deposited on the surfaces was greater during the cake removal stage than during the cake drying stage. This finding parallels the trend observed in the airborne copper concentrations detected by the nearby area air samples. One contradiction did exist between the wipe and area air samples: the area air concentrations were greater during the third cake removal stage than during the second cake removal stage; however, the wipe samples showed just the opposite results. Finally, there was a tendency for the south wipe samples, which were near the exhaust fan in the south wall of the room, to contain higher quantities of copper than found on the north wipe samples.

TABLE 13. DEPOSITION OF COPPER ON SURFACE AREAS OF THE FILTER PRESS DURING CAKE DRYING AND CAKE REMOVAL STAGES

Cycle/Stage	Copper in Milligrams Per Square Meter	
	North Area	South Area
#2/Cake Drying	0.2	0.8
#2/Cake Removal	0.9	19
#3/Cake Drying	0.2	0.8
#3/Cake Removal	0.6	1.1

Worker Dermal Exposures

The exposed skin surfaces for all of the operators were comprised of the head, neck, and lower arm areas. Since Operator B-1 did not wear any work gloves, his hands were also potential sites for dermal exposures. The routes by which copper could have been deposited upon these exposed skin surfaces were by: airborne aerosols, direct contact with the influent and effluents, and contact with surfaces in the filter press room contaminated with copper particles.

The air and wipe sampling results indicate that the airborne copper concentrations made aerosol deposition on the exposed skin surfaces a negligible consideration. Contact with the influent was precluded by the containment of the influent within pipes from the storage tank to the filter press. Furthermore, at the few places where the operators had to open/close valves and turn on/off a pump to control the influent, no leaks were observed at sealing points that could have directly resulted in dermal exposures to the influent.

Although both the filtrate and the filter cake could have been directly contacted by the operator, observations of the normal operating procedures indicated that direct contact with either of these materials was very unlikely. The only locations for the operators to contact the filtrate were at the discharge spigots or inside the open collection trough. Since the spigots and the collection trough were recessed inside of the outer frame of the press and located at a height comparable to the operators' knees, casual or inadvertent contact with the filtrate was greatly inhibited. Also, the low copper concentrations in the filtrate meant that substantial wetting of the skin surfaces would have been required to effect any significant chemical exposure (e.g., one liter of filtrate contained less than 1 mg of copper). The other effluent, the filter cake, was retained within the recessed chambers until it was discharged into the hopper. The operators could have had direct contact with the filter cake only if they had reached into the filter press and grabbed the cake as it fell from the chambers into the hopper. This activity did not occur.

Finally, the surfaces in the filter press room were covered with a fine layer of green dust. This color would indicate that the source of this dust was the sludge processed in the filter press. Based upon the results of the wipe tests, this dust apparently has gradually accumulated over time. The operators would have incurred skin exposures to this dust while manipulating the various control valves, or upon incidental contact with any surface that they happened to place their lower arms or hands.

The most noticeable hand contact by the operators with objects in the filter press room was observed during the cake removal stage. After several chamber plates had been mechanically separated and the filter cloths cleaned, the operators would grab the outer edges of the plates and slide the plates slightly forward to insure that they were correctly aligned with the filter cloths and would close properly at the start of the next filtration operation. In addition, the operators occasionally held onto the side of the press for support while peering into the press to inspect the filter cloths for cake residue. The surfaces of the plates and the press frame were especially prone to contamination by particles of filter cake due to their close proximity to the cake removal process. Of all the materials entering or exiting the filter press, the filter cake contained the highest copper concentration. While all of the operators probably incurred some dermal exposures on their lower arms due to this incidental contact with the filter press surfaces, only Operator B-1 could have received exposures on both hands since he was the only operator that did not wear gloves during any of the filtration stages.

Mass Balance (Chemical Release)

Prior to presentation of the results on the mass balance of the influent and effluents for the filter press, the leaks and spills observed during the filtration operations are discussed. These leaks and spills represent releases of chemicals that would not have been included in the other mass measurements. Five separate leaks and spills were documented with each one of these releases occurring during every monitored filtration operation. These five releases were as follows:

1. The air valve (V14) to the press allowed a leak of one drop of sludge feed every 10 seconds during the sludge filtering stage. The material from this leak fell onto the floor of the lower level. The amount of sludge feed released from this leak was estimated to be 12 mL during each sludge filtering stage.

   $$\frac{1 \text{ drop}}{10 \text{ s}} \times \frac{60 \text{ s}}{\text{min}} \times \frac{1 \text{ mL}}{20 \text{ drops}} \times 38 \text{ min} = 11 \text{ mL}$$

2. During the sludge filtering stage, six different recessed chamber plates were seen dripping liquid into the cake hopper. Each of these six leaks flowed at a rate of about 1 drop every 2 seconds. After falling into the cake hopper, the liquid seeped through seams of the hopper, and finally fell onto the floor of the lower level. The amount of sludge feed released from these six leaks was estimated to be 340 mL during each sludge filtering stage.

$$6 \text{ leaks} \times \frac{1 \text{ drop}}{2 \text{ s}} \times \frac{60 \text{ s}}{\text{min}} \times \frac{1 \text{ mL}}{20 \text{ drops}} \times 38 \text{ min} = 340 \text{ mL}$$

3. The valve (V4) to the sludge feed pump leaked sludge at a rate of 1 drop every minute. This material fell onto the floor of the waste treatment room. The amount of sludge feed released from this leak was estimated to be 2 mL during each sludge filtering stage.

   $$\frac{1 \text{ drop}}{\text{min}} \times \frac{1 \text{ mL}}{20 \text{ drops}} \times 38 \text{ min} = 2 \text{ mL}$$

4. The majority of the fine mist that was discharged from the filtrate spigots during the cake drying stage fell onto the floor of the lower level directly beneath the collection trough. The quantity of this filtrate mist was sufficient to dampen an area of approximately 1.5 square meters. Assuming that the mist formed a film thickness of 0.25 mm over the dampened area, this

release constituted approximately 375 mL of filtrate per cake drying stage.

$$1.5\ \mathrm{m}^2 \times 0.25 \times 10^{-3}\ \mathrm{m} \times \frac{1000\ \mathrm{L}}{\mathrm{m}^3} \times \frac{1000\ \mathrm{mL}}{\mathrm{L}} = 375\ \mathrm{mL}$$

5. Small fragments of filter cake missed the hopper as the recessed chambers were emptied during the cake removal stage. Approximately one dozen small chunks were caught in the filtrate collection trough, while an equal number fell onto the floor of the lower level. These small fragments of filter cake were approximately 5 cc in volume. Thus, the two dozen filter cake fragments spilled from the filter press comprised a release of approximately 120 cc (5 cc x 24) of cake. Those pieces of filter cake that fell into the collection trough were washed into the effluent sump by the filtrate produced during the succeeding filtering stage.

The liquid leaks identified above in numbers 1 through 3 were associated with sealing points containing sludge feed. However, the liquids observed dripping from these points were clearer in appearance compared to the murky, green color of the sludge. Therefore, the residue and copper concentrations in these leaking fluids may have been lower than in the original sludge. All of the material that fell onto the lower level floor would eventually be washed or swept into a floor drain.

Table 14 presents the volumes of sludge processed through the filter press during each of the first three filtration operations. Since the cross-sectional area of the sludge storage tank was 4.67 m^2, 4,670 liters of sludge would be present in the cylindrical tank for each meter of depth.

Table 15 presents the volumes of filtrate measured in the effluent tank during each of the first three filtration operations. The volume formula for the effluent tank was identical to that for the sludge feed storage tank. However, since the effluent tank was completely empty prior to the start of the filtration operations, the volume of filtrate collected in the tank during the first cycle included the capacity of the tank's dished bottom.

Table 16 presents the mass of filter cake weighed in one recessed chamber, and the subsequent extrapolated mass for all 22 chambers, for each of the first three filtration operations.

TABLE 14. VOLUMES OF SLUDGE PROCESSED BY FILTER PRESS

Elapsed Time of Filtering, minutes	Distance from Top of Tank to Surface of Sludge, meters	Change in Distance from Previous Time, meters	Volume of Sludge Filtered During Time Interval, liters	Cumulative Total of Sludge Filtered, liters (± 280 L)
FIRST OPERATION				
0	1.37	--	--	--
20	1.61	0.24	1,120	1,120
36	1.73	0.12	560	1,680
53	1.80	0.07	330	2,010
57	1.81	0.01	50	2,060
SECOND OPERATION				
0	1.81	--	--	--
11	2.01	0.20	930	930
19	2.09	0.08	370	1,300
26	2.13	0.04	190	1,490
THIRD OPERATION				
0	2.13	--	--	--
14	2.32	0.19	890	890
24	2.43	0.11	510	1,400
32	2.47	0.04	190	1,590

TABLE 15. VOLUMES OF FILTRATE PRODUCED BY FILTER PRESS

Filtration Operation	Distance from Top of Tank to Surface of Filtrate, meters Start	Finish	Change in Distance, meters	Volume of Filtrate, liters (± 280 L)
1	3.50	2.92	(1)	1720
2	3.05	2.79	0.26	1210
3	2.83	2.59	0.24	1120

(1) Volume = Volume in spherical section (bottom) + Volume in cylindrical section

= 1110 liters + (3.05 - 2.92 meters)(4670 liters/meter)
= 1110 liters + 610 = 1720 liters

TABLE 16. MASSES OF FILTER CAKE PRODUCED BY FILTER PRESS

Filtration Operation	Number of Chamber Selected for Weighing	Mass of Filter Cake in Selected Chamber, kg	Mass of Filter Cake for all 22 Chambers, kg (± 5 kg)
1	#10	15.35	338
2	#12	15.21	335
3	#15	15.39	339
Average		15.32	
Standard Deviation		0.09	

In Table 17, the pertinent field measurements and laboratory analyses (from Tables 7, 14, 15, and 16) have been integrated to yield a mass balance (excluding spills) on the filter press for each of the first three filtration operations.

TABLE 17. MASS BALANCE RESULTS (Composite Data)

		Cycle	
Parameters	1	2	3
Influent (Sludge Feed)			
Mass of sludge, kg	2,150	1,570	1,660
Mass of residue in sludge, kg	90	80	90
Mass of liquid in sludge, kg	2,060	1,490	1,570
Mass of total copper in sludge, kg	2.9	2.0	1.9
Mass of soluble copper in sludge, g	0.5	0.4	0.4
Effluents (Filtrate and Filter Cake)			
Filtrate			
Mass of filtrate, kg	1,720	1,210	1,120
Mass of residue in filtrate, kg	20	10	10
Mass of liquid in filtrate, kg	1,700	1,200	1,110
Mass of total copper in filtrate, g	1.0	1.0	0.9
Mass of soluble copper in filtrate, g	0.9	0.9	0.9
Filter Cake			
Mass of filter cake, kg	338	335	339
Mass of residue in filter cake, kg	113	98	96
Mass of liquid in filter cake, kg	225	237	243
Mass of total copper in filter cake, kg	5.3	3.0	2.1
Mass of soluble copper in filter cake	could not analyze		

The percent differences between the effluent and influent masses (excluding spills) are presented in Table 18, and were calculated using the following equation:

$$\text{Percent Difference} = [(\text{effluent} - \text{influent})/((\text{effluent} + \text{influent})/2)] \times 100\%$$

$$\text{Percent Difference} = [((M_F + M_C) - M_S)/(((M_F + M_C) + M_S)/2)] \times 100\% \quad (6)$$

where

M_S = mass of material in the sludge feed

M_F = mass of material in the filtrate

M_C = mass of material in the filter cake

TABLE 18. PERCENT DIFFERENCES IN MASS BALANCE RESULTS

Difference Between Influent and Effluent Parameters	Percent Differences Cycle 1	2	3
total masses	- 4.4	- 1.6	- 13
residue masses	39	30	16
liquid masses	- 6.8	- 3.6	- 15
total copper masses	59	40	10

Although the average percent difference between the overall effluent and influent masses was -6.3% (range of -1.6% to -13% with a sample standard deviation of 5.9%), the average percent difference between the total copper masses in the effluent and influent was 36% (range of 10% to 59% with a sample standard deviation of 24%). The error in measuring the depths of the sludge feed and filtrate in their respective storage tanks was estimated to be about ± 3 cm. Consequently, applying this error to both the initial and the final measurements in each cycle yields a maximum error of ± 280 liters in the volumes of the sludge feed and the filtrate for each cycle. The error in weighing the filter cake collected from a single recessed chamber was estimated at ± 0.22 kg. Therefore, applying this error to the calculation for the weight of filter cake contained within all 22 recessed chambers produces a maximum potential error of ± 5 kg in the filter cake measurement for each cycle. The mass of total copper was a very small fraction of the total mass comprising the process streams. Although the large masses of the process streams "masked" errors attributable to field sampling and measurement techniques in the overall mass balance results, the very small quantities of total copper magnified these errors in the copper mass balance values.

Despite this inaccuracy with the total copper mass balance computations, a judgment concerning the chemical releases from a filter press can still be made. As discussed at the beginning of this report, if the objective of this particular filter press is to extract metals from the influent, then the copper in the filtrate must be considered a chemical release when discharged. The mass balance figures do indicate that this filter press was highly effective in removing copper from the influent and retaining it in the filter cake. During each filtration operation, the total volume of filtrate from the filter press yielded a chemical release of approximately 1 gram of total copper even though the sludge feed contained on the average approximately 2300 grams of total copper.

It was reported above that the spills and leaks observed during the filtration operation consisted of a series of drips from valves and a few fragments of filter cake that missed the hopper. The small amounts of the materials and their locations in the midst of an industrial plant environment made effective collection of the materials in the quantity needed for laboratory analysis an impractical task. Thus, the mass of the spills and leaks could not be quantitated through laboratory analyses for inclusion into the chemical release calculations.

However, the total copper released from those spills and leaks can be roughly estimated utilizing the laboratory analytical data obtained from the bulk samples (Tables 7 and 17). The three leaks dripping sludge feed released approximately 470 mg of total copper, assuming that the copper concentration in the leaked material equaled the level found in the sludge feed (i.e., worst case).

(11 + 340 + 2 mL)(1.05 g/mL)(1 kg/1000 g)(1266 mg Cu/kg sludge)

= 470 mg

The filtrate mist observed wetting the floor during the cake drying stage released approximately 0.3 mg of total copper if the mist's copper concentration equaled the value found in the bulk filtrate samples.

(375 mL)(0.732 mg Cu/L filtrate)(1 L/1000 mLs) = 0.3 mg

The fragments of filter cake that missed the collection hopper released approximately 600 mg of total copper if the fragments retained the same density as found in the filter cake measurements (an average of 337 kg of filter cake within a total filtration volume of 0.70 m^3).

$$(120 \text{ cc})(1 \text{ m}^3/10^6 \text{ cc})(337 \text{ kg}/0.70 \text{ m}^3)(10{,}360 \text{ mg Cu/kg}) = 600 \text{ mg}$$

Consequently, the total copper chemical release from the filtration unit operation was approximately 2.1 grams, or slightly less than 0.1 percent of the 2300 grams of total copper processed in an average filtration cycle.

Total Copper Release = Exhaust air + sludge feed leaks + filtrate + filtrate mist + filter cake spills

= 23 mg + 470 mg + 1 g + 0.3 mg + 600 mg = 2.1 g

SEALING POINTS

Of the 37 sealing points that were associated with the filtration operation, 3 of them (valves V1, V2, and V3) were inaccessible due to insufficient clearance for maneuvering the instruments next to the points. The monitoring results for the 34 sealing points that were accessible are summarized below.

1. The RAM-1 did not detect any aerosol concentrations above the total dust background levels (10 $\mu g/m^3$) at any of the pumps, valves, or connections.

2. The RAM-1 did detect aerosol concentrations above background levels at all 26 open-ended lines. The instrument readings at these points were as follows:

   a. An aerosol concentration of 400 $\mu g/m^3$ was recorded at each of the 23 filtrate spigots.

   b. The aerosol concentration at the filtrate collection trough was also 400 $\mu g/m^3$.

   c. The aerosol concentration at the point where the filtrate pipe discharges into the filtrate sump (lower level of the room) was 1000 $\mu g/m^3$.

   d. The aerosol concentration at the top of the filtrate sump was 300 $\mu g/m^3$.

3. It must be noted that the RAM-1 measures TOTAL aerosol concentration; it is not capable of identifying a particular species of aerosol contaminant (e.g., copper aerosol). Since the measurable concentrations detected by the RAM-1 were all produced by sealing points

discharging filtrate, an effluent that laboratory analyses have shown to contain low amounts of copper, the copper content of those aerosol concentrations would be similarly very low.

4. No readings above background vapor levels were detected by the Trace Gas Analyzer at any of the sealing points.

QUALITY ASSURANCE

The field audit encompassed the sample collection activities of the entire second and third filtration operations. The auditor (from SwRI) compiled a written report (presented in Appendix C) detailing the observations made of the field sampling activities and submitted it to the Project Manager. The documentation on the observations, conclusions, and recommendations was divided into five general categories and are summarized below (the quotation marks contain statements directly taken from the Field Auditor's report):

1. Documentation of Worker Activities and Plant Operational Characteristics: "The data recorded appears to be adequate to provide the necessary information for inclusion in the in-plant assessment report." No recommendations were made.

2. Documentation of Air Sample Collection: "No problems were observed in documenting sample collection. A pump malfunction occurred during the observation of one work task, and the pump failure was appropriately noted." No recommendations were made.

3. Calibration Procedures for Air Samplers: Observations on the calibration and data documentation procedures were noted. No deviations from the QA Sampling and Analysis Plan were observed. A recommendation was made that: "If data is to be corrected to standard conditions, it is suggested that the field-measured pressure be checked against a reliable source." Since this study was measuring aerosol concentrations, correction of sampled air volumes to standard conditions was not applicable (per Occupational Safety and Health Administration's Instruction CPL 2-2.20A CH-1, Industrial Hygiene Technical Manual, Chapter 2, paragraph A.2.c.).

4. Sample Collection and Handling Techniques: "Samples were collected in a manner consistent with the Sampling and Analysis Plan for this project." The Field Auditor noted the difficulty in obtaining a representative bulk sample of the sludge feed as its level dropped in the storage tank. "However, with multiple attempts,

sufficient representative sample was obtained." Recommendations included a more generalized preprinted sample label that would permit field entries and color coding of sample labels for the type of samples.

5. Conclusion: "The sampling effort was compressed into a very intense effort over 33 hours which was conducted with no major deviation from the procedures specified in the quality assurance protocols."

The data reports generated in the laboratory included: the analytical results of the samples (regular and collocated), calibration data (standards, initial calibration verification, and continuing calibration verification), duplicate analytical results, spike results (laboratory and preparation), and blank values (continuing calibration blanks and laboratory preparation blanks).

The spiked samples were prepared through the addition of known concentrations of copper to the digestates of the air and bulk samples. This procedure only indicates "analytical" accuracy (i.e., the ability of the atomic absorption technique to measure copper in the digested solution). This procedure does not show the "total" accuracy of the analytical process since it does not quantify the ability of the digestion procedure to recover the copper from the sample matrix (e.g., air filter, sludge, filter cake, etc.). Hence, equation (2) on page 36 reflects this analytical accuracy, not total sample accuracy. Using equation (2), the copper analyses on eight spiked air samples produced percent recovery accuracies ranging from 90 to 121 percent (average was 106 percent), with only one result greater than the desired goal of • 15 percent. The copper analyses on five spiked bulk and wipe samples yielded percent recovery accuracies ranging from 100 to 113 percent (average was 104 percent).

Collocated air samples were air samples placed immediately adjacent to a "primary" air sample and collected over the same time period. The primary air samples (results presented in Table 9) were analyzed for copper at SwRI in accordance with NIOSH Method 7029 with the exception that the atomic absorption was accomplished with a graphite furnace rather than direct aspiration flame technique. The graphite furnace technique (detection limit equaled 0.025 micrograms of copper per sample filter) was selected to increase analytical sensitivity on the filter samples. The collocated air samples were analyzed for copper at a laboratory accredited by the American Industrial Hygiene Association using flame atomic absorption (the laboratory did not possess the capability to perform the graphite furnace technique on air samples). Four of the five collocated sample analyses were reported as possessing copper masses that were below the detection limits of the flame atomic absorption technique (detection limit equaled 3 micrograms of copper per sample filter). The graphite furnace analyses on the corresponding primary air samples yielded copper amounts which were less than the detection limits reported for the collocated samples. For the one pair of primary and collocated samples in which both laboratories reported detectable quantities of copper, the precision percent difference using equation (4) was 7.4 percent (Table 19).

For the bulk samples, collocated samples and duplicate analyses were accomplished. Collocated bulk samples were second samples collected from the process streams at the same time and locations that the "primary" bulk samples were collected. Thus, the precision percent differences (equation 4) between the primary and collocated bulk samples are measures of the precision involving both sample collection and laboratory analysis. A duplicate analysis, entailed taking a portion of the original bulk sample and performing a second analysis on that original bulk sample. Since the duplicate analysis involved the total laboratory procedure (sample preparation and analysis), equation (3) is a measure of the laboratory's precision in analyzing the bulk samples. Utilizing the data presented in Table 7, the precision percent differences between the primary and collocated bulk samples and between duplicate analyses of primary bulk samples are presented in Table 20. Regarding the 15 percent difference between the total residue analyses of the primary and collocated sludge feed samples, duplicate laboratory analyses on the primary sample were within 3 percent of one another. Consequently, the large precision percent difference between the primary and collocated sludge feed samples is probably attributable to sampling technique errors rather than analytical faults. The incomplete mixing of the sludge feed in the storage tank could prompt major discrepancies between samples.

TABLE 19. COLLOCATED AIR SAMPLE RESULTS

Primary (SwRI) Air Sample		Collocated Air Sample	
Number	Copper Concentration ($\mu g/m3$)	Number	Copper Concentration ($\mu g/m3$)
AE-F04R-C	3.9	AE-F05C-C	< 23
AR-C06R-C	16	AR-C09C-C	< 43
AR-B10R-C	4.8	AR-B09C-C	< 14
AE-C03R-C	130	AE-C05C-C	140
AE-B04R-C	2.6	AE-B05C-C	< 15

TABLE 20. PRECISION PERCENT DIFFERENCES

Parameter	Precision Percent Difference, % Collocated Samples* (Equation #4)	 Duplicate Analyses (Equation #3)
Sludge Feed, Total Residue	15	3
Sludge Feed, Total Copper	4	4
Sludge Feed, Soluble Copper	5	-
Sludge Feed, Density	< 1	0
Filtrate, Density	-	0
Filter Cake, Total Residue	11	-
Filter Cake, Total Copper	10	6

*Goal in the QA Project Plan was a percent difference of ± 15%.

SECTION 8

DISCUSSION

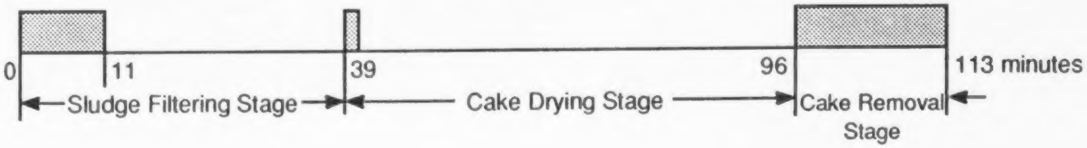
This in-plant assessment vividly demonstrated to the survey team that the successful isolation of worker exposures and chemical releases to a single unit operation, and to the sub-tasks within that unit operation, is heavily dependent upon comprehensive advanced planning and exceptional cooperation from the plant employees. Furthermore, the simultaneous collection of exposure samples, worker scenario information, and chemical release measurements will intrude into the normal work routine of the employees.

Detailed observations of the work scenarios revealed a large difference between the time required for the filter press to complete a filtration operation and the time that the filter press actually required the operators' presence. For almost 50 percent (54 minutes) of the 113 minutes needed to complete an average filtration operation, the filter press was unattended while the operators were doing other duties outside the filter press room. In addition, more than two-thirds (28 minutes) of the 39 minutes required for the sludge filtering period does not necessarily demand the constant presence of the operator. Consequently, the 113 minutes required for Plant 50's filter press to complete a filtration operation could easily cause an operator to incur an actual exposure time of about 31 minutes. Therefore, equating the duration of a filter press operation to an operator's exposure, particularly if the operation possesses a cake drying/dewatering stage, could overestimate this exposure.

However, if a single worker was responsible for the operation of multiple filter presses, the "free times" within the various stages could permit the operator to stagger the stages of the individual filter presses and operate them simultaneously. Figure 15 illustrates that if there were 3 presses (identical to press A) in Plant 50, and a single operator were to begin the sludge filtering stages for those presses at 11-minute intervals (the time required to accomplish the starting procedures and monitor the press for leaks), that operator could perform the various tasks on the 3 presses and finish in a period of 147 minutes. During that span of time, the operator would accrue a total exposure duration of 93 minutes (3 presses times 31 minutes per press), which is equivalent to 63 percent of the total time. In comparison, an operator assigned to one filter press

▨ Period of Time That Operator Is Performing a Task Within a Stage.

(a) Worker operates only one (1) press; exposure time is 27% (31 of 113 minutes) of operation.


0
11
39
96
113 minutes
Sludge Filtering Stage
Cake Drying Stage
Cake Removal Stage

(b) Worker opeates three (3) presses by staggering the starts at 11-minute intervals; exposure time is 64% (93 of 147 minutes) of total operational time.

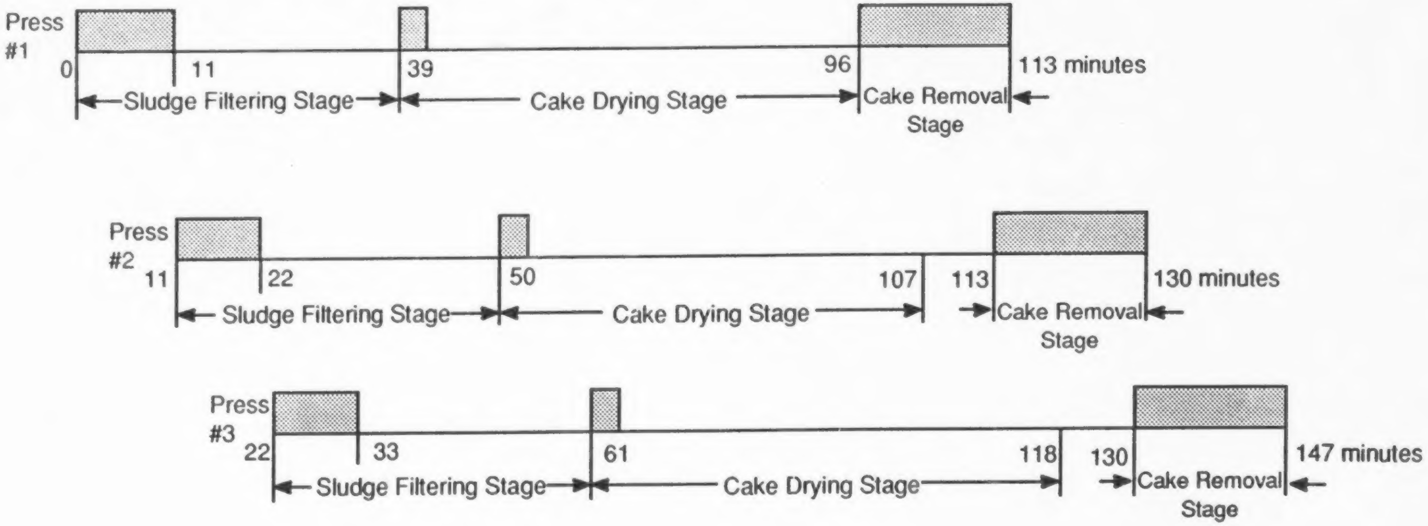

Press #1
0
11
39
96
113 minutes
Sludge Filtering Stage
Cake Drying Stage
Cake Removal Stage
Press #2
11
22
50
107
113
130 minutes
Sludge Filtering Stage
Cake Drying Stage
Cake Removal Stage
Press #3
22
33
61
118
130
147 minutes
Sludge Filtering Stage
Cake Drying Stage
Cake Removal Stage

Figure 15. Exposure Time versus Number of Filter Presses Operated.

accumulates an exposure duration that is 27 percent (31 out of 113 minutes) of the total time.

Therefore, the factors that determine a worker's exposure time to the filter press operation are:

1. The time duration of the unit operation.
2. The number and duration of "automatic" tasks in the operation that do not require the worker's presence.
3. The number of presses that the worker can operate at a given time.

The quantity of target chemical, total copper, was a very small portion of the material processed through the filter press. As such, the methods used to accomplish a mass balance on the filter press were found to be too insensitive to accurately or precisely quantitate the mass of total copper. Recognizing its limitations, the mass balance revealed that:

1. Approximately 2.3 kilograms of total copper were processed through the filter press during an average filtration operation.
2. The concentration of total copper in the sludge feed and the filter cake averaged 0.1 and 1.0 percent by weight, respectively. The copper concentration in the filtrate was at least three orders of magnitude less than that found in the sludge feed.
3. The filter press efficiency in removing total copper from the sludge feed was about 99.9 percent. The percentage of total copper in the sludge feed that was insoluble was also about 99.9 percent.
4. The concentration of soluble copper in the filtrate effluent was greater than the soluble copper concentration in the sludge feed.
5. The mass of total copper released in the filtrate during an average filtration operation was 1 gram. The mass of total copper that was released into the air, and remained airborne until exhausted out of the filter press room, was approximately 23 milligrams during an average filtration operation. The total mass of copper that was released by the filter press must be termed a "rough estimate" since the mass of total copper in spills and leaks could not be directly measured. The leaks and spills consisted of three valves that slowly dripped sludge feed, filtrate mist blowing from the spigots during the cake drying stage, and small

fragments of filter cake that missed the hopper. The mass of total copper in these spills and leaks was approximated as 1.1 grams. The sum of these chemical releases was 2.1 grams. Thus, the quantity of total copper released from the filter press was roughly estimated to be about 0.1 percent of the total copper (2.3 kg) processed through the filter press.

6. In Plant 50, the chemical releases were a small percentage of the total mass processed through the filter press primarily because: (1) there were few sealing points and they were in good condition, (2) the hopper beneath the filter press effectively captured the falling pieces of filter cake, and (3) the press was so effective in removing copper that the subsequent filtrate stream contained practically no copper. However, as can be seen in Table 21, if there had been more or larger spills and/or leaks at Plant 50, the total chemical releases from the filter press could have been drastically larger. The data in Table 21 presents the mass of the various materials at Plant 50 that would yield a copper release of 1 gram. If a facility operated a filter press in such a manner that spills and leaks were routine, the magnitude of the chemical releases could be much higher than observed at Plant 50 even if the filter press also effectively removed the target chemical and produced a very "clean" filtrate.

TABLE 21. EQUIVALENT MASSES OF MATERIAL AT PLANT 50 REQUIRED TO RELEASE ONE (1) GRAM OF TOTAL COPPER

Material	Mass of Material, in kilograms, Required to Release One (1) Gram of Copper
Sludge Feed	0.8
Filtrate	1370
Filter Cake	0.1

The operators' TWA exposures to total copper during the filtration operation ranged from 3.1 to 25 $\mu g/m^3$, with a geometric mean of 6.4 $\mu g/m^3$ and a standard deviation of 2.2. Evaluation of the inhalation exposure data and the worker scenarios reveal that:

1. On the average, the filter cake removal stage accounted

for 72 percent of the operators' exposure to copper during the filtration operation. An operator's exposure during the cake removal stage should be dependent upon the quantity of filter cake particles entering his/her breathing zone and the concentration of the target chemical in the filter cake. According to the sample analyses, the filter cake removed by Operator C-1 had the lowest mass of copper in comparison to that cake removed by Operator A-1 (first iteration) and Operator B-1. However, the copper exposure incurred by Operator C-1 was greater than the exposures encountered by the other two operators. Therefore, while the concentration of the target chemical in the filter cake may influence the broad scope of the inhalation exposures for all of the press operators (e.g., mg or μg of copper per cubic meter of air), the techniques utilized by an operator to remove the filter cake appear to be the factors that determine that worker's exposure to "within an order of magnitude."

2. Regarding the operator (C-1) that incurred the largest inhalation exposure, close inspection of that worker's technique showed that he stood closer to, and more frequently leaned over, the side of the filter press while scraping the cake residue off the filter cloths. These actions consistently placed his breathing zone closer to the filter cloths than observed with the other operators. Operator C-1 was also the only operator that elected to wear respiratory protection during the cake removal stage. It is unknown if this worker felt it necessary to wear a respirator to protect himself because his chosen work technique caused him to be in close proximity to the filter cloths, or if he wanted to wear a respirator and its protection/security eventually enabled him to adopt an "aggressive" work technique.

3. Although the other two stages of the filtration operation (sludge filtering and filter cake drying) comprised 85 percent of the time required to complete a filtration operation, the operators incurred very little exposure during these stages (28 percent of the overall TWA exposure). Further examination of the exposure data in these stages reveals that:

   a. There appeared to be no correlation between an operator's movement in the room and the resulting inhalation exposure. The only common denominator among the operators' work paths was that they were never required to be in close proximity to the filter press.

b. Although the blowing of compressed air through the filter cake generated a mist in the vicinity of the filtrate collection trough during the cake drying stage, the airborne concentrations of copper at the breathing zone levels were actually less than those present during the sludge filtering stage. This may have been caused by the filtrate's very low copper content.

4. Between the third and fourth cycles of the filter press monitored in the study, Press A was utilized to process a different waste sludge. The filter press and piping were not cleaned prior to the fourth cycle. It is not known whether this intermediate waste stream processing affected the worker exposure measurements from the fourth cycle. The field sampling crew chief reported more foam in the collection trough of Press A during the fourth cycle and attributed it to the change in feedstock between cycles three and four. Nevertheless, the feedstock change does not alter the chemical release and mass balance findings since these were conducted only on the first three cycles. The field sampling team was unaware what feedstock was processed through Press A prior to cycle one, other than it did not come from the study's feed tank. Neither the filter press nor the piping was cleaned before cycle one. Consequently, the situation is the same for cycle four and cycle one. In addition, Operator A performed the work on both cycle one and cycle four.

Observations of the workers indicated that any dermal exposures incurred during the sludge filtering and filter cake drying stages would be the result of casual or incidental contact of the hands with surfaces contaminated with copper particles. In the filter cake removal stage, the operators often grabbed the sides of the filter press for support while inspecting the filter cloths for cake residue and they also used their hands to push the chamber plates into position. Wipe samples indicated that the amount of copper deposited onto surfaces of the press from a single filtration operation was not dramatic, but possibly significant contamination could gradually accumulate over time. However, any dermal exposures on the operator's hands could be readily precluded by the wearing of cotton work gloves. Two of the three operators observed in this study did wear gloves during all stages of the filtration operation.

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APPENDIX A: WORKER SCENARIOS

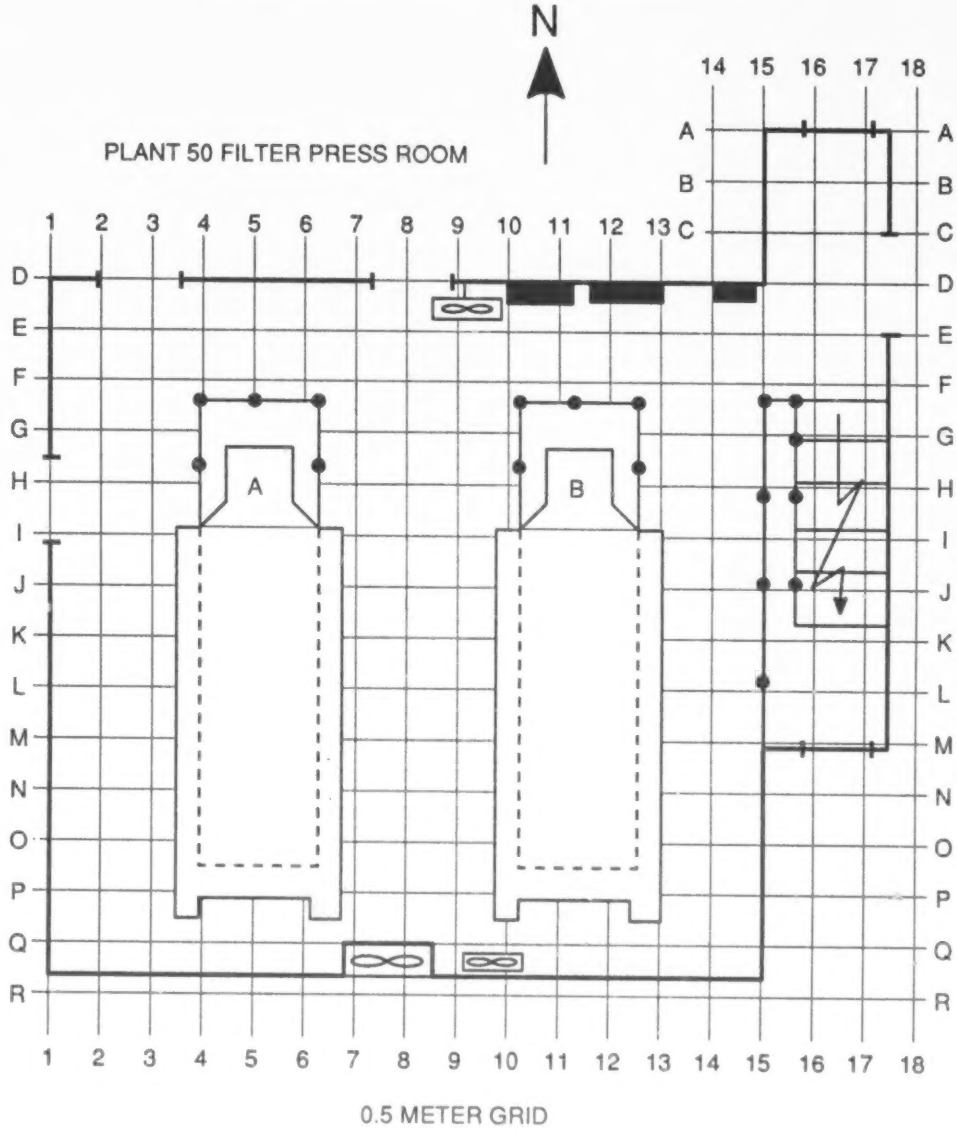

N
PLANT 50 FILTER PRESS ROOM
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
A B C D E F G H I J K L M N O P Q R
A
B
0.5 METER GRID

Figure A-1. Plant 50 Filter Press Room.

WORK SCENARIO DATA SHEET

PLANT No:_______ DATE:__________________ UNIT OP:__________________

PRODUCTION/ EQUIPMENT CYCLE:__________________ ITERATION NUMBER:_____ TOTAL NUMBER OF EMPLOYEES INVOLVED IN SCENARIO:________

PROTECTIVE EQUIPMENT:____

EMPLOYEE NAME AND TITLE:____

INHALATION SAMPLE NUMBERS:____________________________ DERMAL SAMPLE NUMBERS:__________________

DESCRIPTION OF WORK ACTIVITIES AND ASSOCIATED EXPOSURE CONDITIONS		
EMPLOYEE LOCATION	DEFINE SOURCE OF EXPOSURE - PATH AND DISTANCE FOR CONTAMINANTS TO REACH EMPLOYEE - POSITION AND MOVEMENT OF EMPLOYEE DURING SCENARIO	TIME
	(CONTINUATION PAGE)	

GENERAL NOTES, PAGE______ WORKER PATH CHART, PAGE______ DERMAL EXPOSURE DIAGRAM, PAGE_______

Figure A-2. Work scenario data sheet.

TABLE A-1. OPERATOR A-1 WORK SCENARIO DURING THE FIRST SLUDGE FILTERING STAGE

Event	Description of Operator's Activities	Elapsed Time, Minutes
1	Entered room at east doorway to initiate filtering.	0
	Walked to control panel for Press A.	
2	Activated hydraulic ram, closed press, and turned pneumatic valve on while standing in front of control panel.	1
	Walked to pump/valve area outside of east doorway.	
3	Opened valves and started sludge feed pump.	4
	Re-entered room and walked to a position 0.75 meters from Press A.	
4	Stood at position observing for any sludge leaks from press frames.	6
	Walked to a position adjacent to Press B, 1.5 meters from Press A.	
5	Stood at position. Observed sludge filtering while leaning against Press B.	19
	Walked back to pump/valve area outside east doorway.	
6	Inspected performance of pump and tranquilizer.	22
	Re-entered room and walked to a position 1.6 meters from Press A.	
7	Stood at position. Observed sludge filtering while leaning against Press B.	56
	Walked back to pump/valve area outside east doorway.	
8	Closed valves and stopped sludge feed pump.	57

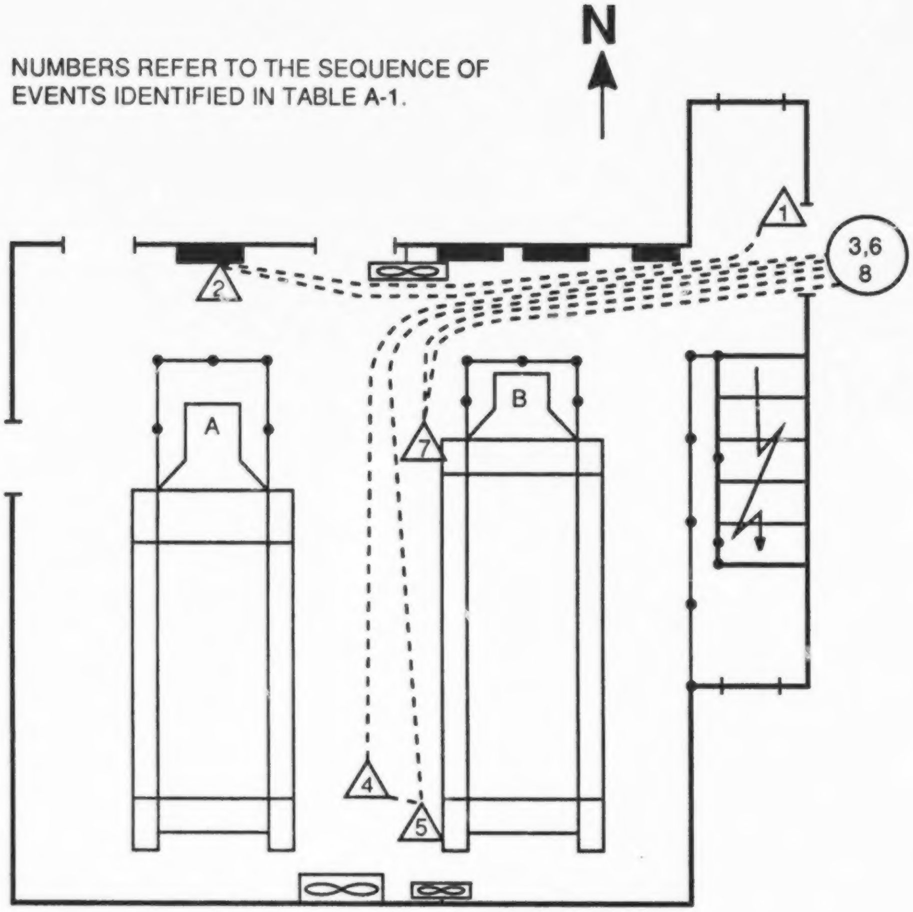

N
NUMBERS REFER TO THE SEQUENCE OF
EVENTS IDENTIFIED IN TABLE A-1.
1
2
3,6
8
A
B
7
4
5

Figure A-3. Operator A-1 Work Path During the First Sludge Filtering Stage.

TABLE A-2. OPERATOR B-1 WORK SCENARIO DURING THE SECOND SLUDGE FILTERING STAGE

Event	Description of Operator's Activities	Elapsed Time, Minutes
1	Entered room at east doorway to initiate filtering.	0
	Walked to control panel for Press A.	
2	Activated hydraulic ram, closed press, and turned pneumatic valve on while standing in front of control panel.	2
	Walked to pump/valve area outside east doorway.	
3	Opened valves and started sludge feed pump.	4
	Re-entered room and walked to a position within 0.25 meters of Press A.	
4	Stood and observed flow of filtrate from spigots.	4.5
	Walked back to pump/valve area outside east doorway.	
5	Inspected performance of pumps and tranquilizer.	5.0
	Re-entered room and walked to a position about 1.25 meters from Press A.	
6	Stood at that position observing filtrate.	8.0
	Walked towards the rear of the filter press at a position 0.75 meters from Press A.	
7	Stood and observed flow of filtrate.	9.0
	Exited the room and stood on platform outside east doorway.	
8	Checked performance of pump again.	10
	Walked back into the room until halfway down Press A, 1.25 meters from the press.	

Continued...

TABLE A-2 (CONT'D)

Event	Description of Operator's Activities	Elapsed Time, Minutes
9	Stood and observed filtrate flowing out of spigots.	11
	Walked to log sheet hanging on north wall next to control panel.	
10	Annotated log sheet	12
	Walked to the front of Press B, 1.6 meters from Press A.	
11	Observed filtering of sludge while standing adjacent to Press B.	25
	Walked to the pump/valve area.	
12	Turned off pump and valves.	26

NUMBERS REFER TO THE SEQUENCE OF EVENTS IDENTIFIED IN TABLE A-2.

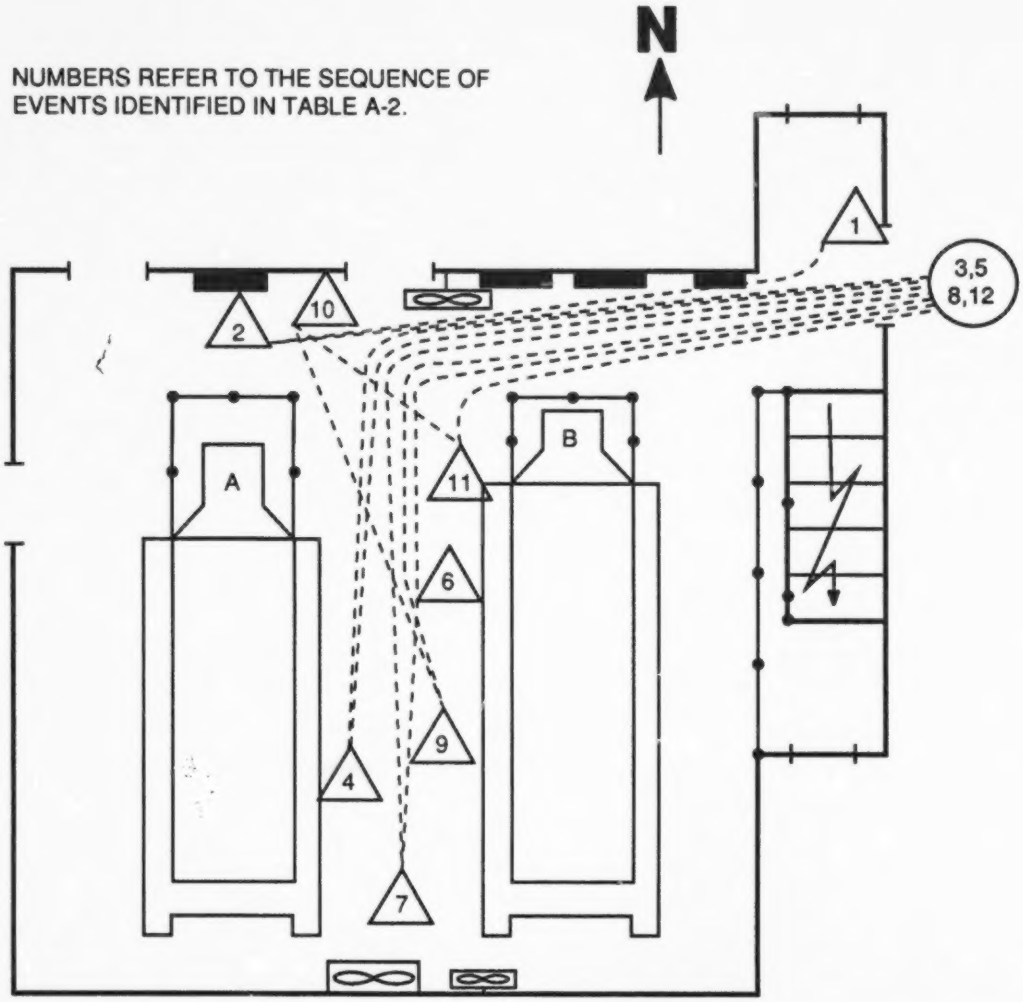

N
1
3,5
8,12
2
10
A
B
11
6
9
4
7

Figure A-4. Operator B-1 Work Path During The Second Sludge Filtering Stage.

TABLE A-3. OPERATOR C-1 WORK SCENARIO DURING THE THIRD SLUDGE FILTERING STAGE

Event	Description of Operator's Activities	Elapsed Time, Minutes
1	Entered room at east doorway to initiate filtering.	0
	Walked to control panel for Press A.	
2	Activated hydraulic motor for ram.	1
	Walked to the side of Press A.	
3	Observed press to insure that it closed properly.	2
	Returned to control panel for Press A.	
4	Finished switching control valves to start filtering.	3
	Walked out the east doorway to pump/valve area.	
5	Opened valves and started sludge feed pump.	4
	Returned to room and walked halfway down length of Press A, at a location 1.3 meters from the press.	
6	Observed flow of filtrate and visually checked for leaks.	6
	Returned to pump/valve area.	
7	Checked performance of pump and tranquilizer.	7
	Re-entered room and walked to a position 1.3 meters from Press A.	
8	Stood and observed flow of filtrate.	8
	Walked to the rear of Press A, 0.9 meters from it.	

Continued...

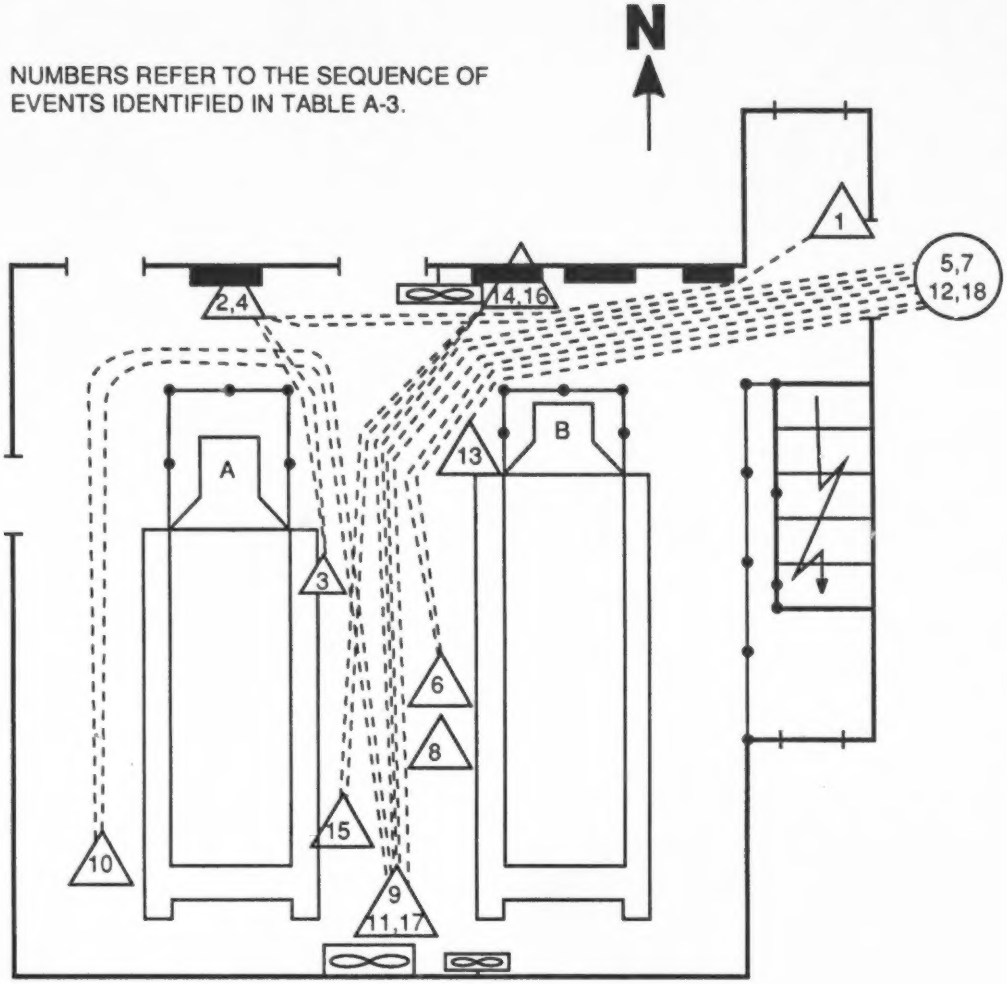
TABLE A-3 (CONT'D)

Event	Description of Operator's Activities	Elapsed Time, Minutes
9	Operator crouched in a squatting position and pointed out a small leak from the press to the Field Auditor.	10
	Walked around the front of Press A and down the opposite side of Press A; stopped at a position 0.5 meters from Press A.	
10	Looked at the filtrate dripping from the leaking press frame.	11
	Walked back to the area between Press A & B, again by going around the front of Press A, and stopped at a position 0.9 meters from Press A.	
11	Stood and talked to Field Auditor.	12
	Walked to pump/valve area outside east doorway.	
12	Inspected performance of sludge feed pump.	14
	Re-entered room and stood next to Press B, about 2.0 meters from front of Press A.	
13	Observed filtration operation.	19
	Walked to control panel for screw conveyor against north wall.	
14	Stood in front of control panel watching filter press.	22
	Walked to the side of Press A.	
15	While standing adjacent to Press A, operator discussed filtering operation with Field Auditor.	26
	Walked back to screw conveyor control panel.	

Continued...

TABLE A-3 (CONT'D)

Event	Description of Operator's Activities	Elapsed Time, Minutes
16	Stood and observed filtering operation.	27
	Walked back to the rear of the filter press, 0.9 meters from Press A.	
17	Stood and observed filtering operation.	31
	Exited the room for the pump/valve area.	
18	Closed valves and stopped sludge pump.	32



NUMBERS REFER TO THE SEQUENCE OF EVENTS IDENTIFIED IN TABLE A-3.

N
1
5,7
12,18
2,4
14,16
A
B
13
3
6
8
15
10
9
11,17

Figure A-5. Operator C-1 Work Path During The Third Sludge Filtering Stage.

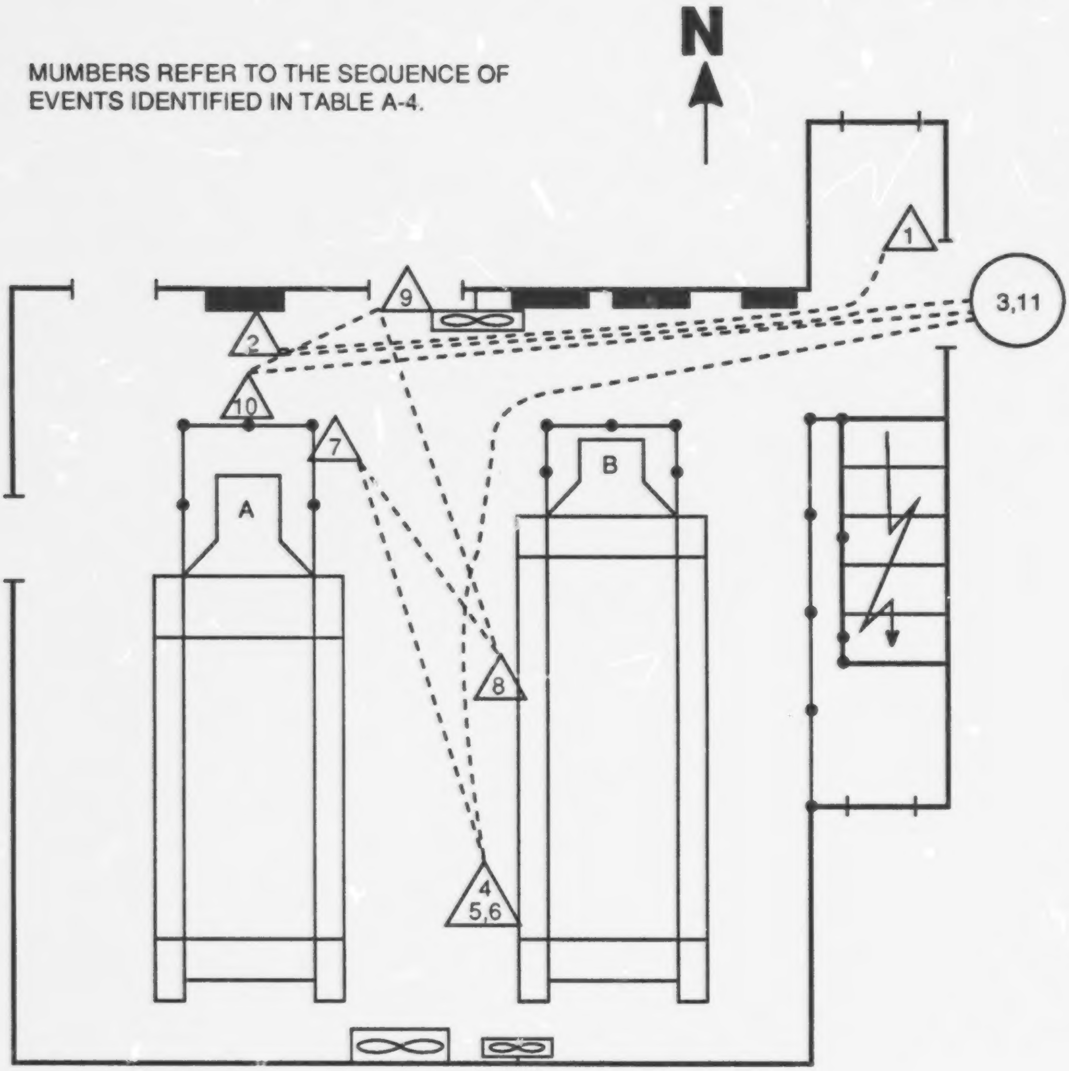
TABLE A-4. OPERATOR A-1 WORK SCENARIO DURING THE FOURTH SLUDGE FILTERING STAGE

Event	Description of Operator's Activities	Elapsed Time, Minutes
1	Entered room at east doorway to initiate filtering.	0
	Walked to control panel for Press A.	
2	Activated hydraulic ram, closed press, and turned pneumatic valve on while standing at control panel.	1
	Walked to pump/valve area outside of east doorway.	
3	Opened valves and started sludge feed pump.	2
	Walked back into the room, went to the rear of Press B, 1.6 meters from Press A.	
4	Stood next to Press B and observed filtering operation.	5
5	At same position, bent over at the waist to show Project Manager details of filtrate spigots.	6
6	Resumed standing position to observe filtration.	8
	Walked to the front of Press A.	
7	Looked at front of Press A.	9
	Walked back to Press B, 1.6 meters from Press A.	
8	Stood and observed filtering process while leaning against Press B.	30
	Walked to northeast door.	

Continued...

TABLE A-4 (CONT'D)

Event	Description of Operator's Activities	Elapsed Time, Minutes
9	Stood at door and observed filtration operation.	34
	Walked to front of Press A.	
10	Observed filtration while leaning on guardrail in front of Press A.	39
	Walked out east doorway to pump/valve area.	
11	Closed valves and stopped sludge feed pump.	40



MUMBERS REFER TO THE SEQUENCE OF EVENTS IDENTIFIED IN TABLE A-4.

N
1
3,11
9
2
10
7
A
B
8
4
5,6

Figure A-6. Operator A-1 Work Path During the Fourth Sludge Filtering Stage.

TABLE A-5. WORK SCENARIO FOR ALL OPERATORS DURING FILTER CAKE DRYING STAGES

Event	Description of Operator's Activities	Elapsed Time, Minutes
1	After closing valves and stopping sludge feed pump, entered room at east doorway.	0
	Walked to control panel for Press A.	
2	Turned pneumatic valve off.	0.5
	Walked to front of Press A.	
3	Leaned over guardrail to adjust controls and check air pressure gauge.	1.0
	Walked to the rear of Press A.	
4	Opened valve to let compressed air flow through filter cake.	1.5
	Walked to east doorway.	
5	Exited room.	2.0
	Remained outside filter press room for a period of time (T). The time periods for the four iterations were, in numerical order: 61, 53, 46, and 55 minutes.	
6	Entered the room at the east doorway.	T + 2.0
	Walked to the rear of Press A.	
7	Closed valve to stop flow of compressed air.	T + 2.5
	Walked to the front of Press A.	
8	Re-adjusted controls. End of stage.	T + 3.0

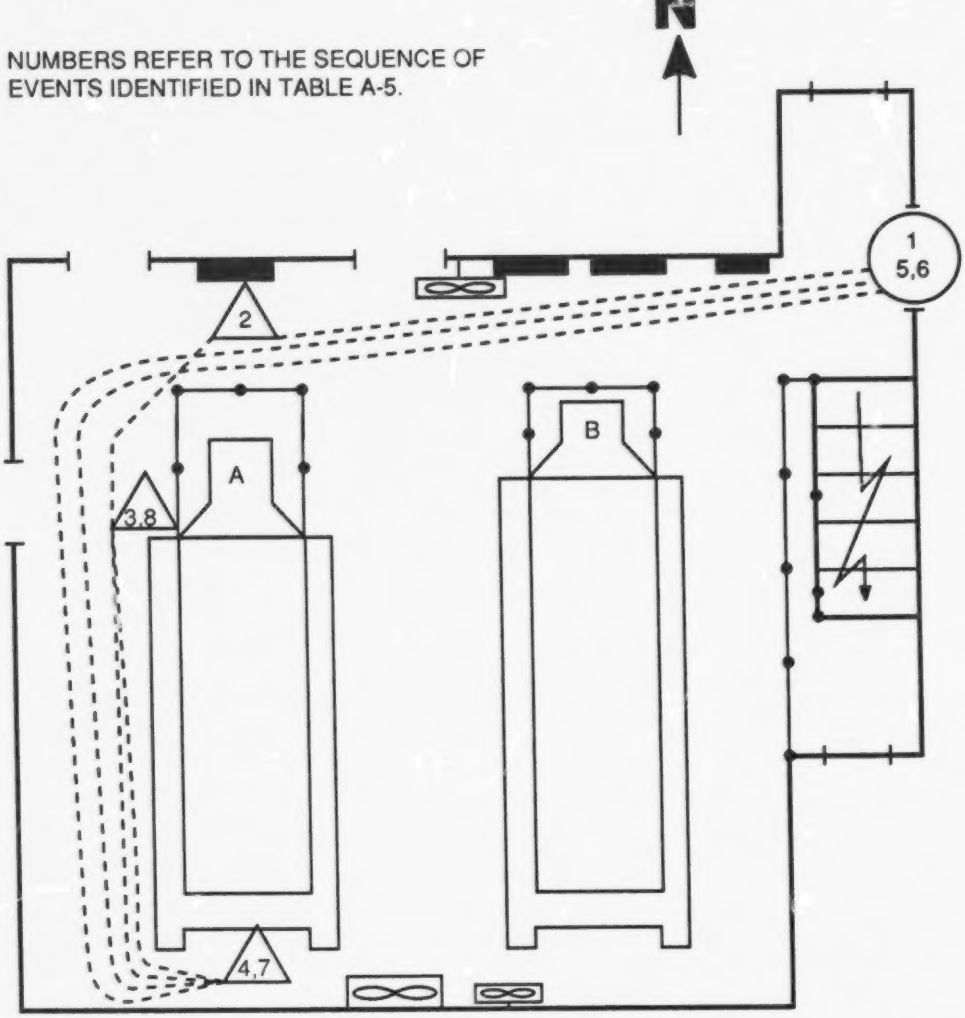

NUMBERS REFER TO THE SEQUENCE OF
EVENTS IDENTIFIED IN TABLE A-5.
N
1
5,6
2
A
B
3,8
4,7

Figure A-7. Work Paths For All Operators During All Iterations of The Filter Cake Drying Stage.

TABLE A-6. GENERAL WORK SCENARIO FOR ALL OPERATORS DURING FILTER CAKE REMOVAL STAGES

Event	Description of Operators' Activities
1	After closing valves at the front of filter press A to stop the filter cake drying stage, the operator walked to the control panel for press A.
2	Standing in front of the control panel, the operator turned on the switch that retracted the hydraulic ram. As the ram retracted, the first recessed chamber opened and most of the filter cake within that chamber fell into the hopper.
3	The operator walked to the control panel for the screw conveyor and turned a switch that activated the screw conveyor.
4	The operator walked to the filtrate trough side of filter press A, near the front, and cleaned the two filter cloths within the first recessed chamber using the wooden pole. When the chamber was opened, the two exposed filter cloths hung down in an inverted "V" shape. The operator stood next to the filter press, facing the front of the filter press with his shoulders at a 45-60 degree angle to the press. Holding the wooden pole with both hands, the operator inserted the pole horizontally at about chest height into the space between the two filter cloths. The operator vigorously struck the front (north) filter cloth with the pole 4-6 times in rapid succession, and then used the end of the wooden pole to scrape residue off of the filter cloth. The operator twisted his torso and pivoted on his feet so that he was facing the rear of the press with his shoulders again at a 45-60 degree angle to the press. The residue on the back (south) filter cloth was then removed in the same manner as the front one. This finished the cleaning of the filter cloths in the first chamber. The operator stood by the filter press and pushed down on the cord to activate the plate separation motor. The chain driven mechanism moved the next plate towards the front of the press and the contents of the next chamber fell into the hopper. The filter cloth cleaning cycle was then repeated until all 22 chambers were empty. Occasionally before the operator opened a chamber to remove the filter cake, he had to wait for the screw conveyor to move the

Continued...

TABLE A-6 (CONT'D)

Event	Description of Operators' Activities
	previously dumped filter cake out of the collection hopper. The operator remained at the side of the filter press during these brief interludes in the process. At the start of the removal stage, the operator was at the front of the press to remove the filter cake from the first chamber. As the removal process progressed through the remaining chambers, the operator gradually shifted his position towards the rear of the press. By the time the operator was removing filter cake from the last chamber, the operator was about 2 meters from his starting position.
5	About midway through the cake removal process, the operators walked to the northeast door to observe the performance of the screw conveyor. (Operator C-1 also made an earlier trip to the door after emptying 5 recessed chambers.) The operators stood at the door for about one minute before returning to the side of the filter press and resuming the filter cake removal process.
6	After the last chamber was emptied, the operators walked to the control panel for the screw conveyor. Once the conveyor had finished transporting the filter cake to the disposal trailers, the operators turned off the conveyor. This action completed the cake removal stage and an iteration of the filtration operation.

NUMBERS REFER TO THE SEQUENCE OF
EVENTS IN TABLE A-6.

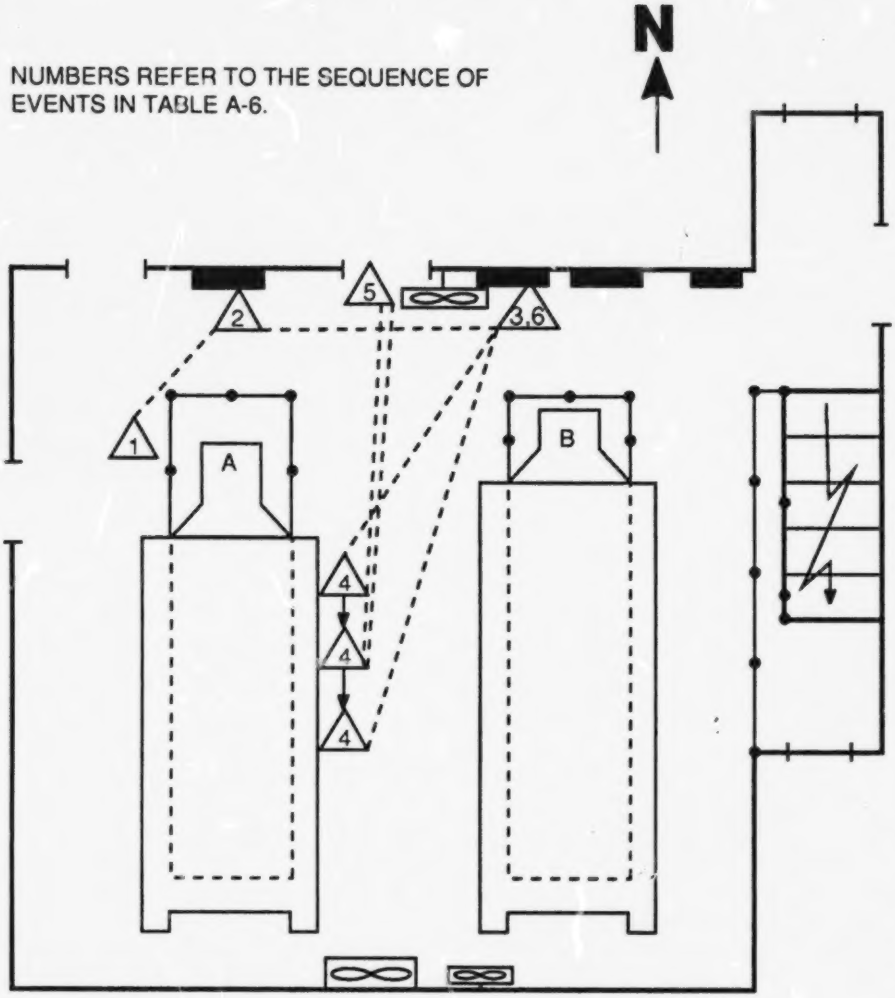


Figure A-8. Work Paths For All Operators During The Filter Cake Removal Stages.

APPENDIX B: PHOTOGRAPHS FROM PLANT 50

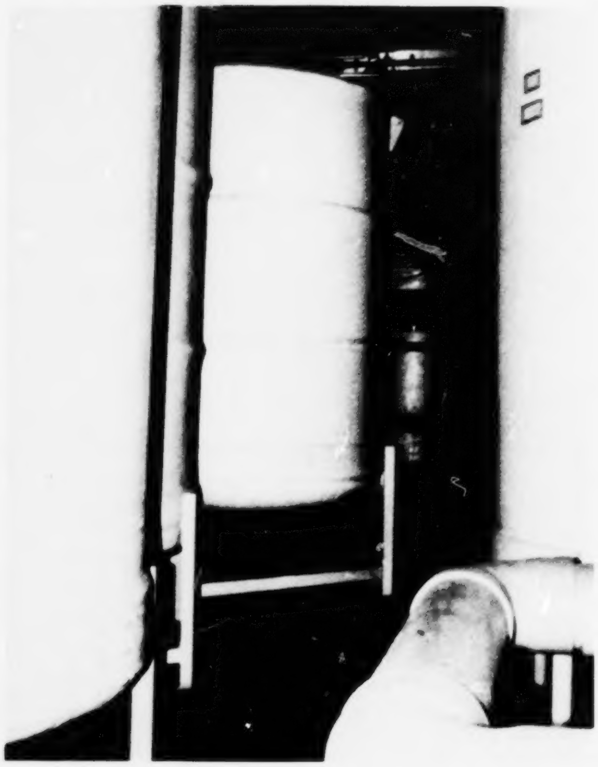


Figure B-1. Sludge feed and filtrate effluent storage tanks. (Located in main waste treatment facility approximately 10 meters from filter press room.)

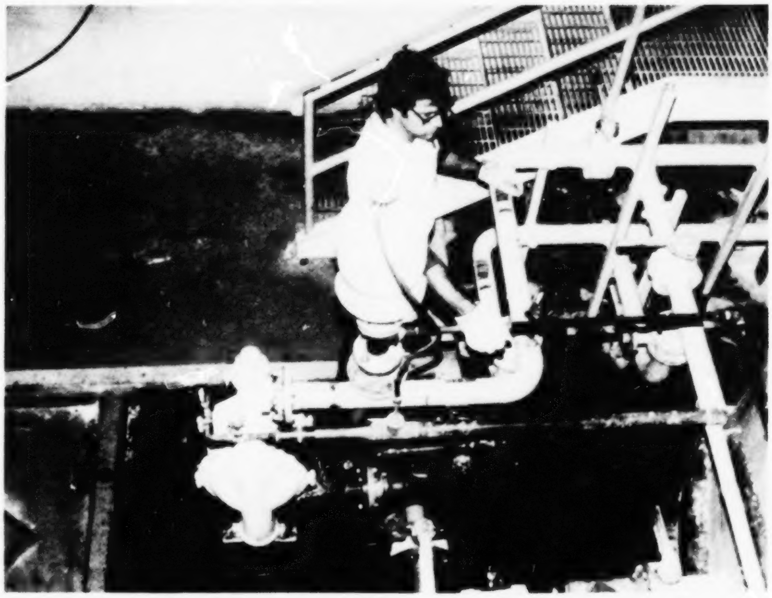


Figure B-2. Operator inspecting sludge feed pumping system during sludge filtering stage. (Stairs behind the operator lead to the east doorway of the filter press room.)

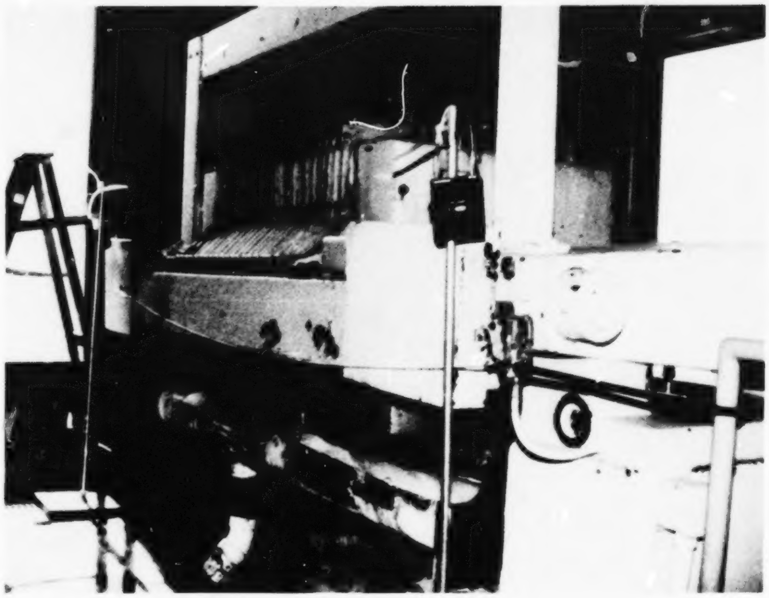


Figure B-3. Filter press A with the recessed chamber plates in the closed position prior to sludge filtering. (Photo shows the side of the filter press containing the filtrate collection trough. The framework housing the hydraulic ram mechanism is at the far right.)

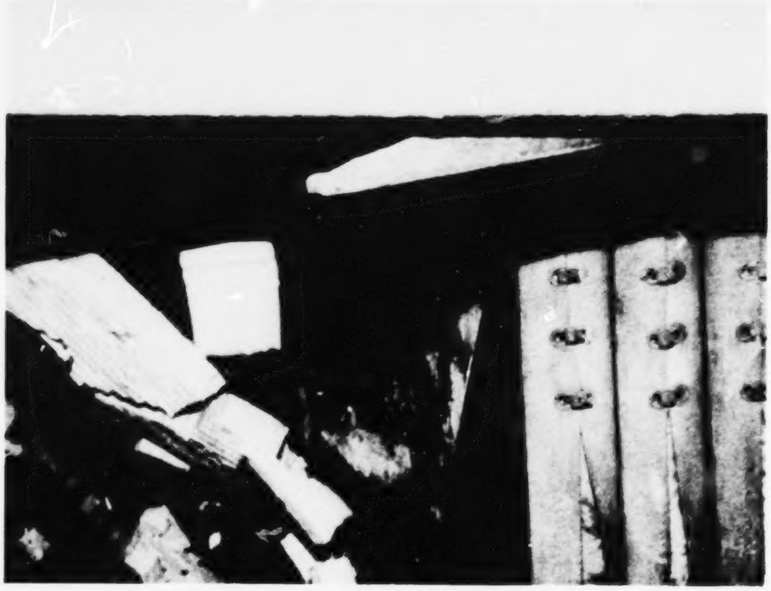


Figure B-4. Filter cake falling from a recessed chamber as it is opened.

Figure B-5. Filter cake residue remaining on filter cloth after recessed chamber has been opened and filter cake has fallen into hopper.

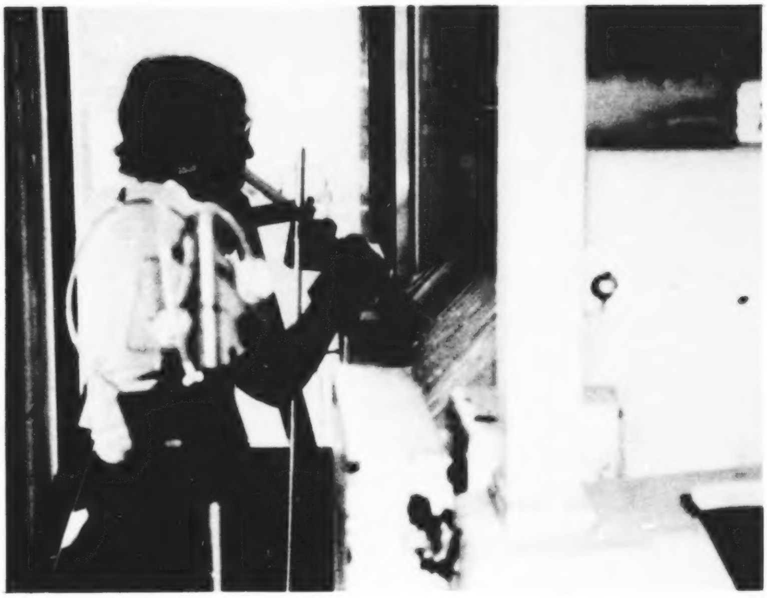


Figure B-6. Operator using a wooden pole to slap the filter cloth to dislodge the filter cake residual from the filter cloth. (Operator is holding pole with both hands to increase impact force.)

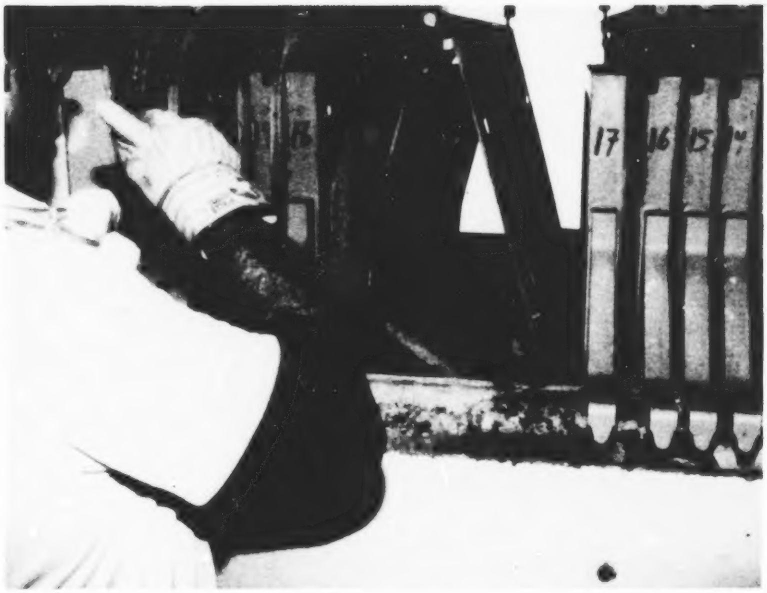


Figure B-7. Operator using a wooden pole to scrape filter cake residual from an area of the filter cloth. (Areas cleaned in this manner are the regions around the central feed slot and in the corners. Note that operator is using just one hand to hold the pole for this cleaning activity.)

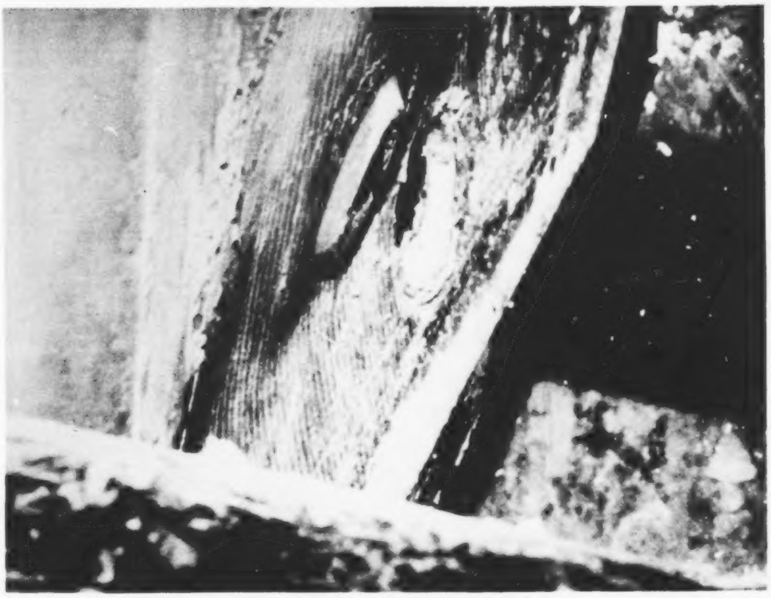


Figure B-8. Filter cake particles falling into hopper as operator slaps the filter cloth with the wooden pole.

APPENDIX C: FIELD SAMPLING QUALITY ASSURANCE AUDIT REPORT

QUALITY ASSURANCE AUDIT

January 25, 1988

Field Sampling Activities
Plant 50 In-Plant Assessment
December 21-22, 1987

Prepared by H. Jac Harding

SwRI Project 01-1236

==

INTRODUCTION

A field audit was conducted during sample collection activities at plant 50 between 5 PM on December 21 and 11:30 AM on December 22. In general this audit consisted of observing the activities of the field crew to confirm that all procedures, protocols, etc. that are documented in the Quality Assurance Project Plan and the QA Sampling and Analysis Plan: In-plant Assessment Study 1 were being followed.

This report is divided into sections related to:

(1) Documentation of worker activities and plant operational characteristics

(2) Documentation of air sample collection

(3) Calibration procedures for air samplers

(4) Sample collection and handling techniques

DOCUMENTATION OF WORKER ACTIVITIES AND PLANT OPERATIONAL CHARACTERISTICS

Various forms and bound field notebooks were used to collect written documentation of both worker activities and operational characteristics during the assessment study. The worker scenario was documented with a sketch of the path taken by the worker during his activities on the Worker Path Chart. Additionally, a limited amount of photographic documentation with both a video camera and a 35-mm still camera was obtained of the work task. The photo documentation will be reviewed by plant 50 personnel prior to release to SwRI. The data recorded appears to be adequate to provide the necessary information for inclusion in the in-plant assessment report.

DOCUMENTATION OF SAMPLE COLLECTION

Parameters associated with air sample collection were recorded on a datasheet that was filled out as the appropriate data were collected. Additionally, general comments, especially as related to the sequence of activities were logged by the field crew chief. The listing of samples according to the Sample Identification Matrix in the QA Sampling and Analysis Plan was used as a master list of samples collected. No problems were observed in documenting sample collection. A pump malfunction occurred during the observation of one work task, and the pump failure was appropriately noted.

CALIBRATION PROCEDURES

The Alpha-1 samplers were calibrated on site using a mini-Buck calibrator. Readings were recorded on the Sample Collection Data Sheet. Measurements of ambient temperature and barometric pressure were also made. The barometer used to measure local pressure was not checked against a local source such as the National Weather Service or a Flight Service Station. If data is to be corrected to standard conditions, it is suggested that the field-measured pressure be checked against a reliable local source.

SAMPLE COLLECTION AND HANDLING TECHNIQUES

Samples were collected in a manner consistent with the Sampling and Analysis Plan for this project. Adequate sample containers, air filter cassettes, and labels were available at the sample collection location. The staging area was limited, but the best use was made of the available space. Unused containers were kept separated from the samples. Samples were labelled immediately after collection and maintained in an ice chest (ambient temperature) after collection. A dual labelling system was used in which one label was placed on the Listing of Environmental Samples and the other on the sample container. Some difficulty was noticed during the collection of a liquid sludge sample prior to the start of a filtration task as the level dropped in the holding tank. A plastic pipe was immersed in the liquid, the upper end of the pipe was sealed, and the pipe was withdrawn with a "plug" of liquid sludge in the pipe. The sample was lifted about 2 m (6 ft) where it was transferred to a sample container. As the liquid level became lower, it became more difficult to maintain the "plug" in the pipe while bringing it up to the top of the tank where it could be placed in the sample container. However, with multiple attempts, sufficient representative sample was obtained. It was also noted that the mixing of the sludge with a single air hose did not provide a uniform suspension of the material, especially as the level in the tank dropped.

All sample labels were pre-coded to eliminate the necessity of a field crew member generating part of the code at time of sample collection. This system required that sample labels be kept separated according to sample matrix code. Future sampling efforts might consider a more general label that would have the final code added at the time of the sample collection in place of a specific label for each sample. Color coding for sample groups is a technique that is suggested for future sample collection (e.g. area air samples and personal exposure samples coded with different colors).

CONCLUSION

The general observation of field sample and data collection activities (worker scenario and plant characteristic documentation) appeared to be adequate and in compliance with both the Quality Assurance Project Plan and the QA Sampling and Analysis Plan. The sampling effort was compressed into a very intense effort over of 33 hours which was conducted with a no major deviation from the procedures specified in the quality assurance protocols.

Distribution: Mary Marshall
David Camann

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